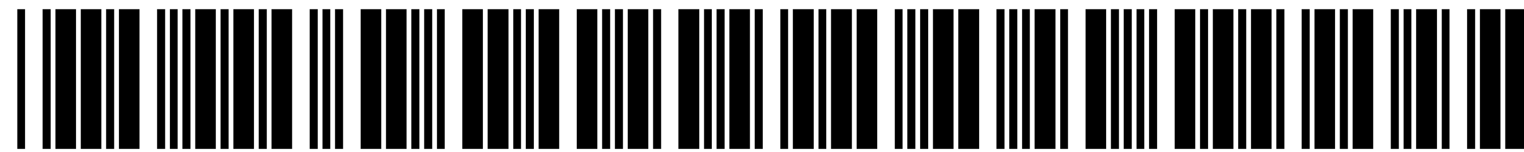

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Alcoe

(10) **Patent No.: US 6,583,354 B2**
(45) **Date of Patent: *Jun. 24, 2003**

(54) **METHOD OF REFORMING REFORMABLE MEMBERS OF AN ELECTRONIC PACKAGE AND THE RESULTANT ELECTRONIC PACKAGE**

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(73) Assignee: **International Business Machines Corporation**, Armonk, NY (US)

(*) Notice: This patent issued on a continued prosecution application filed under 37 CFR 1.53(d), and is subject to the twenty year patent term provisions of 35 U.S.C. 154(a)(2).

Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/300,783**

(22) Filed: **Apr. 27, 1999**

(65) **Prior Publication Data**

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(51) **Int. Cl.**[7] **H05K 5/00**
(52) **U.S. Cl.** **174/52.1**; 228/180.22; 257/738
(58) **Field of Search** 257/780, 738, 257/779; 174/52.1, 52.4, 260, 263; 228/180.22

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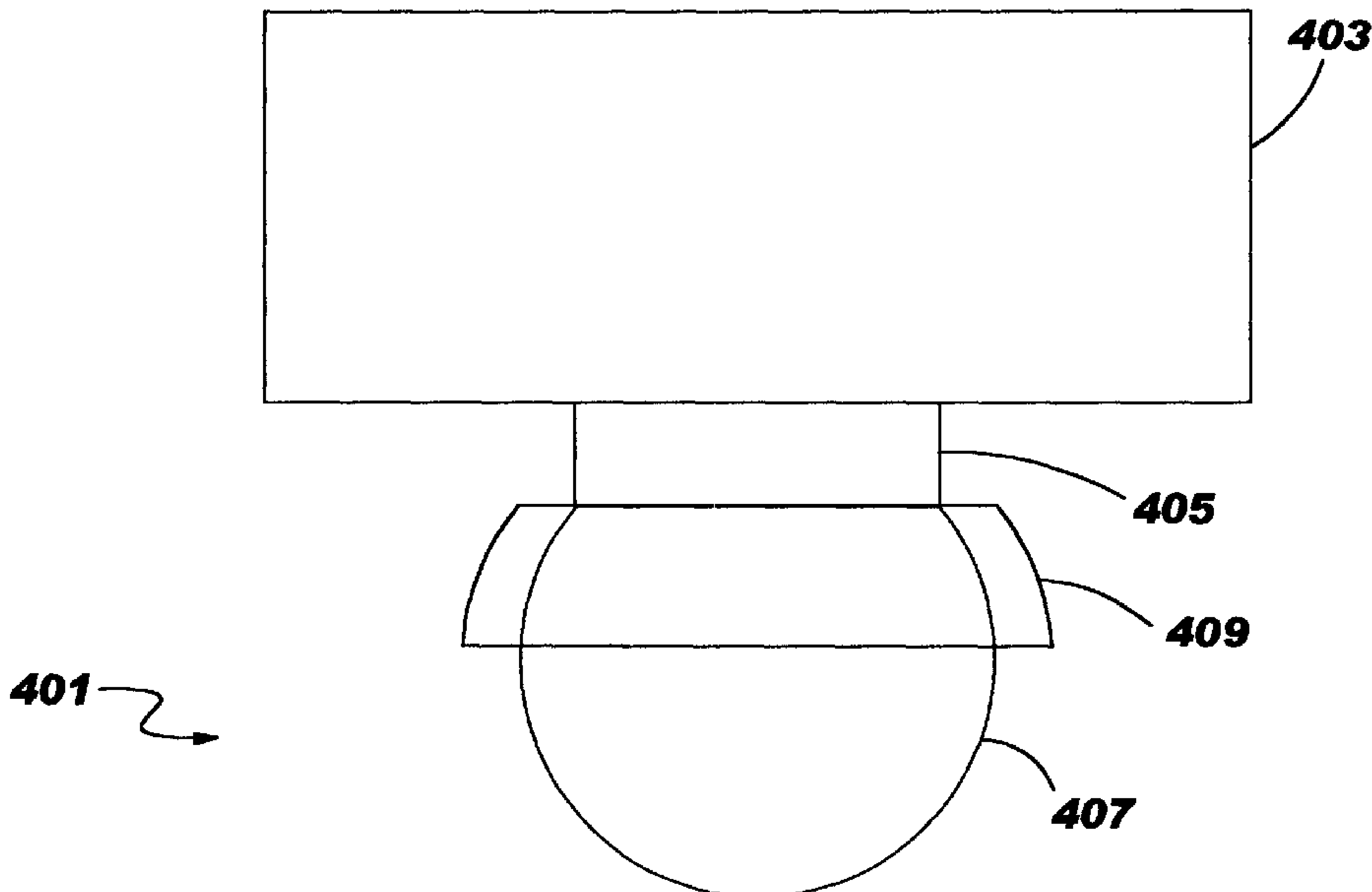
Primary Examiner—Hung V. Ngo
(74) *Attorney, Agent, or Firm*—John A. Jordan; Arthur J. Samodovitz

(57) **ABSTRACT**

An electronic package includes a substrate having a contact pad thereon, a reformable member such as a solder ball positioned on the contact pad, and an elastic member positioned around the reformable member. The elastic member exerts a girdling force on the reformable member so that when the reformable member is softened, the elastic member elongates the reformable member. This elongation accommodates thermal and other stresses between the foregoing substrate and another substrate joined at the free end of the reformable member. An apparatus is also provided for positioning the elastic member on and around the reformable member.

27 Claims, 22 Drawing Sheets



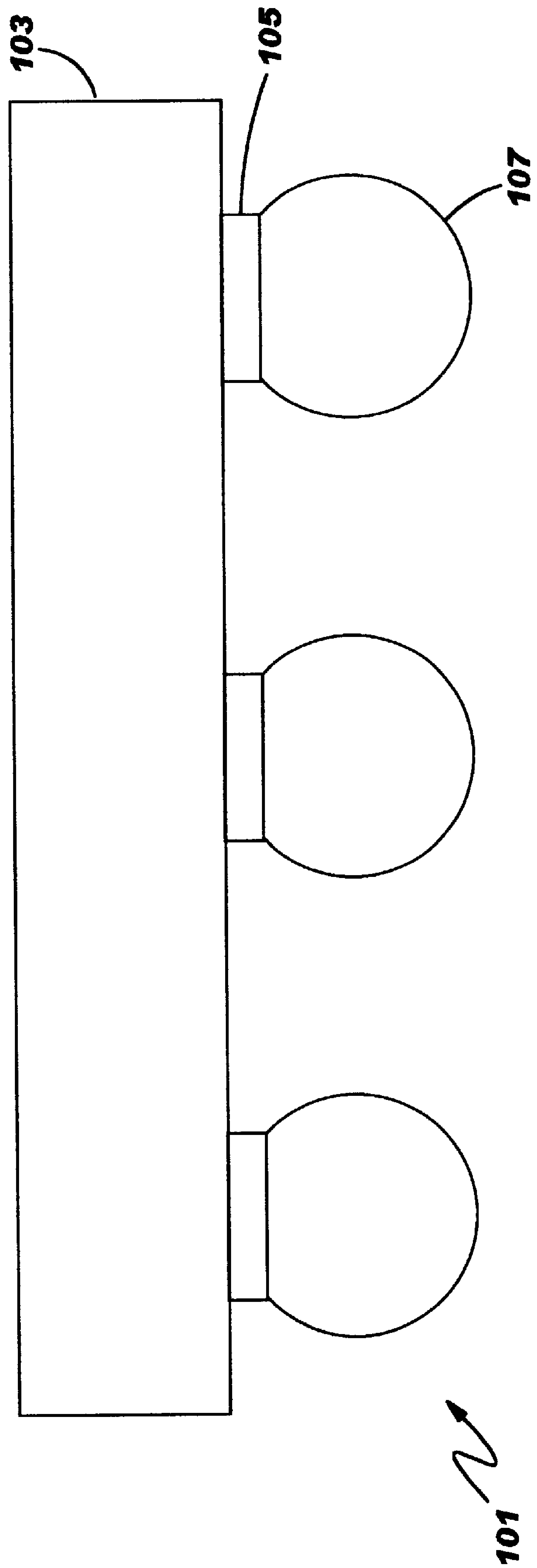


FIG. 1
(Prior Art)

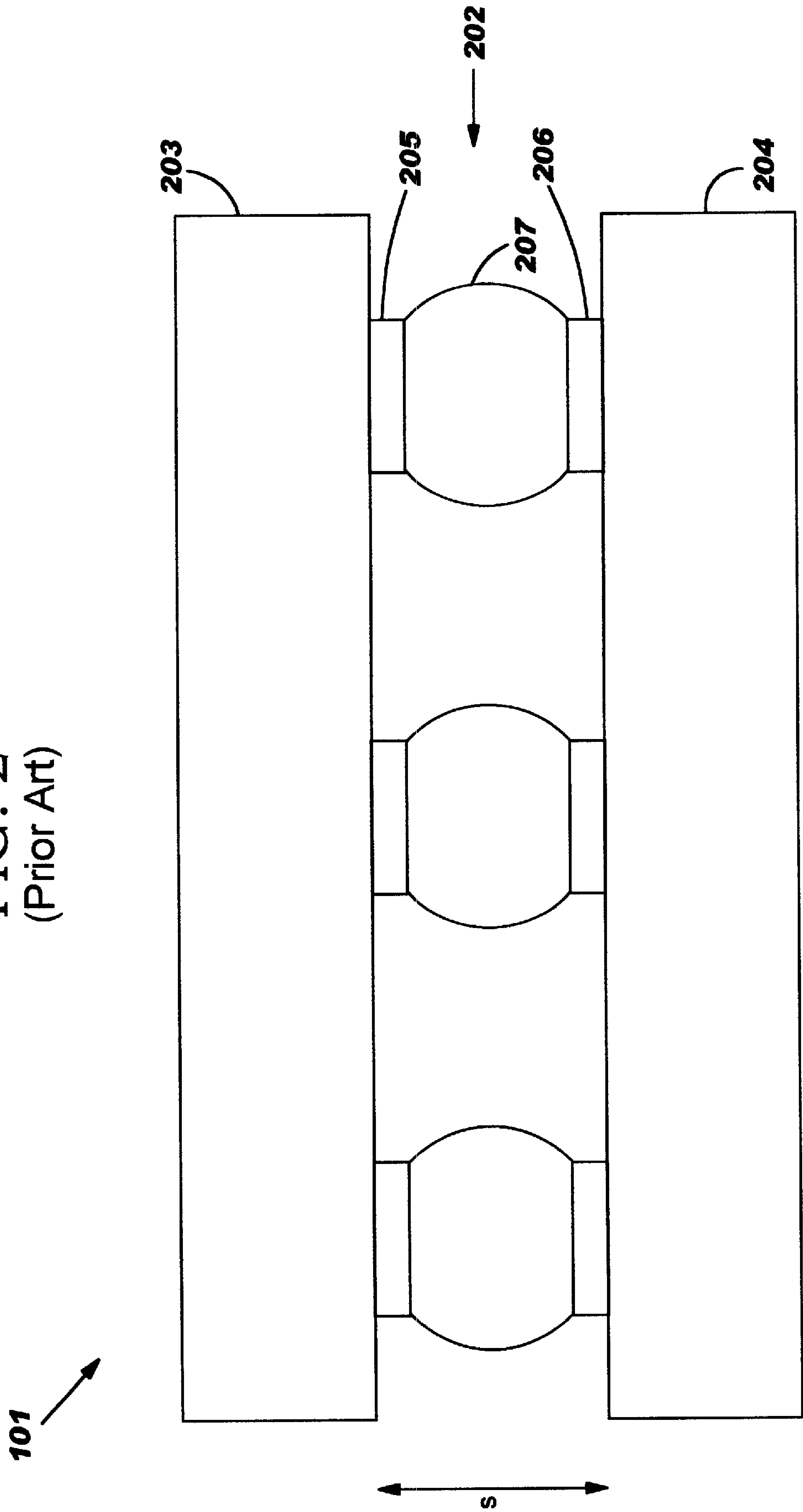


FIG. 2
(Prior Art)

FIG. 3

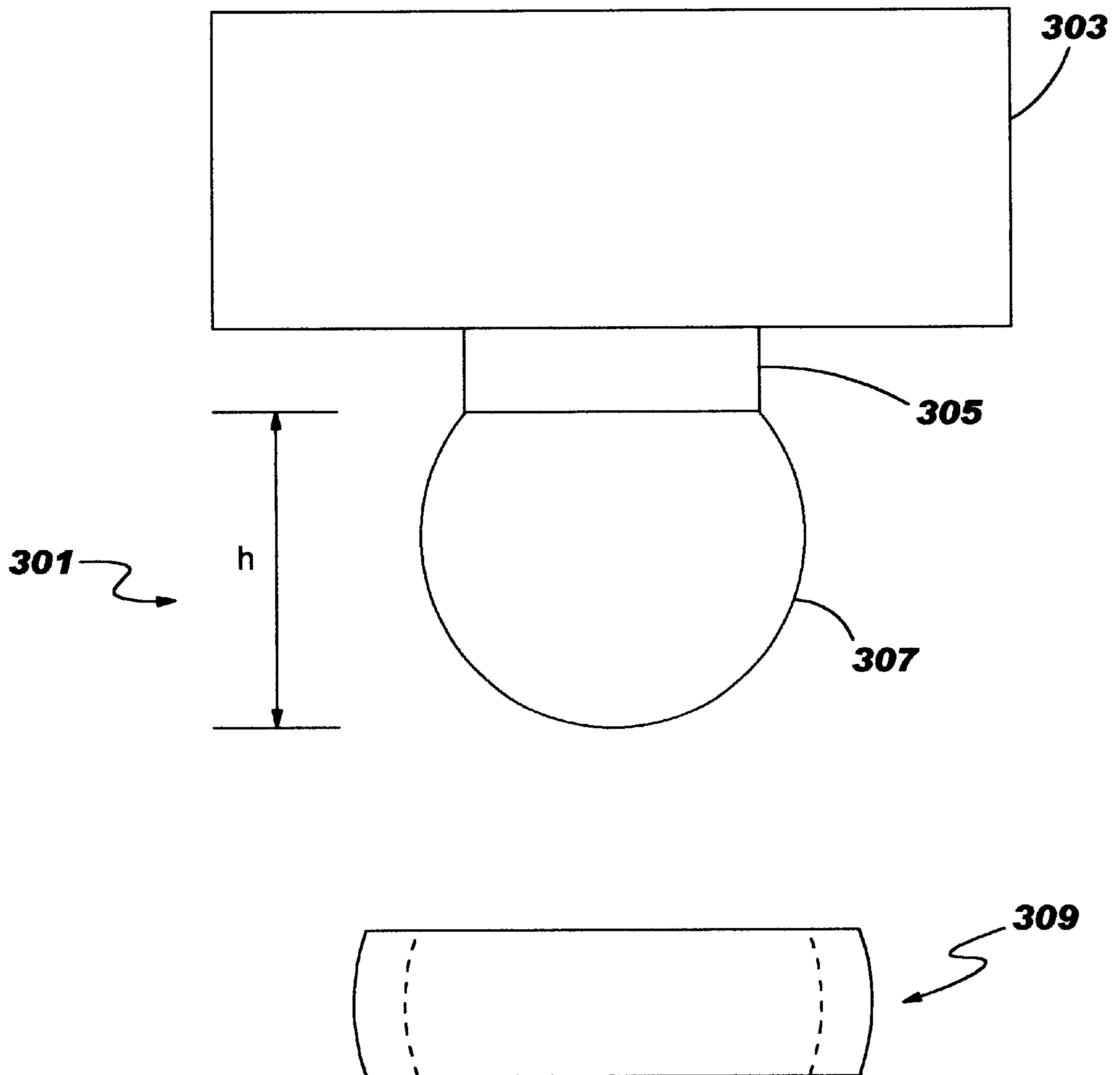


FIG. 4

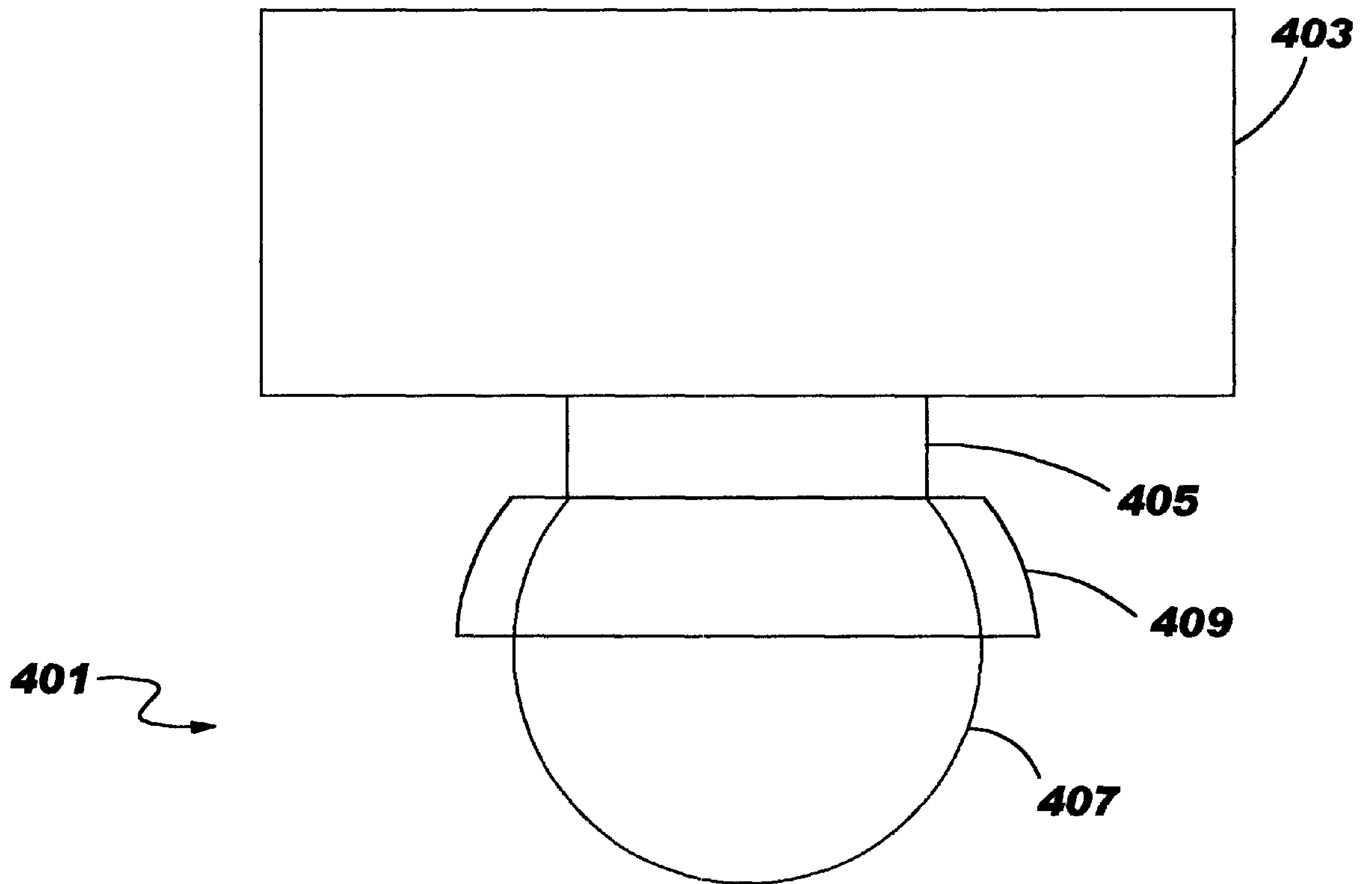
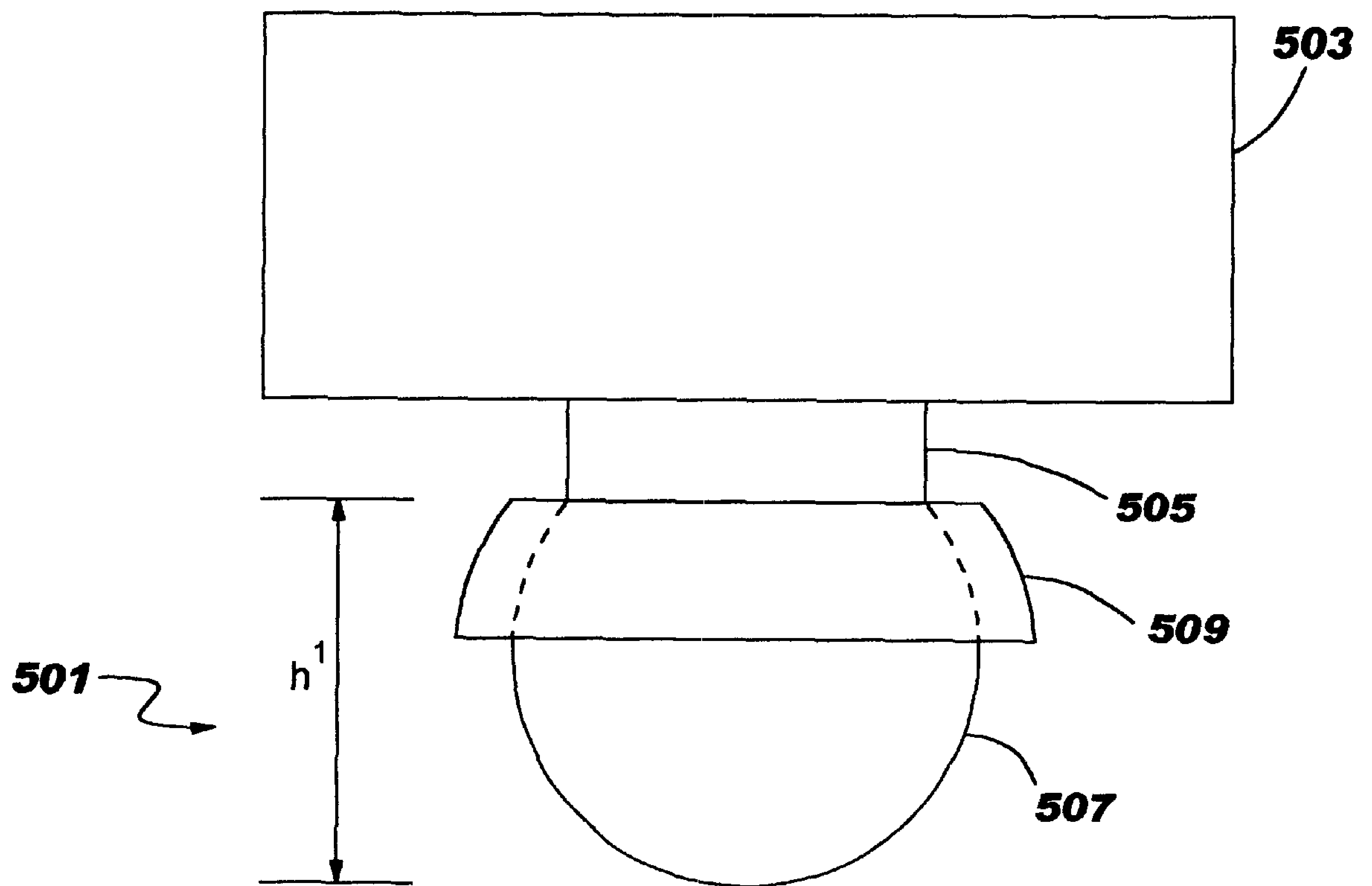


FIG. 5



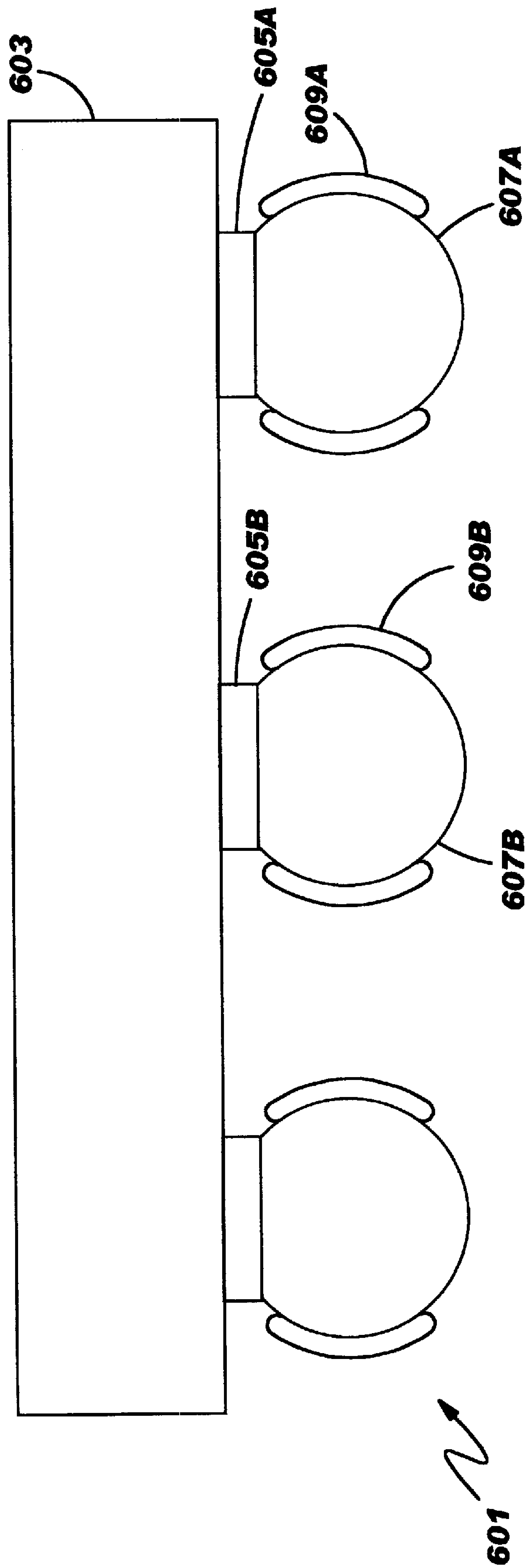


FIG. 6

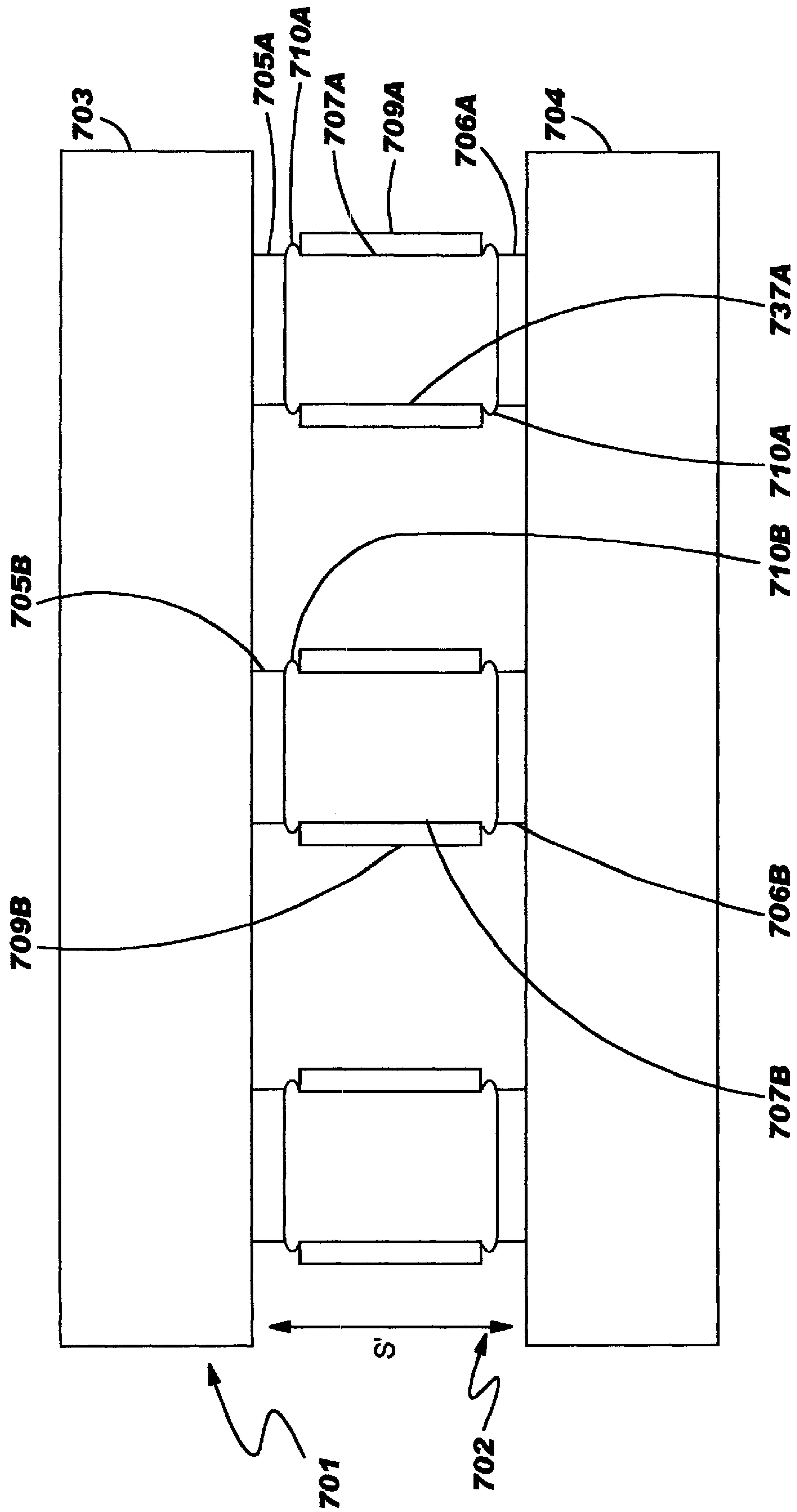


FIG. 7

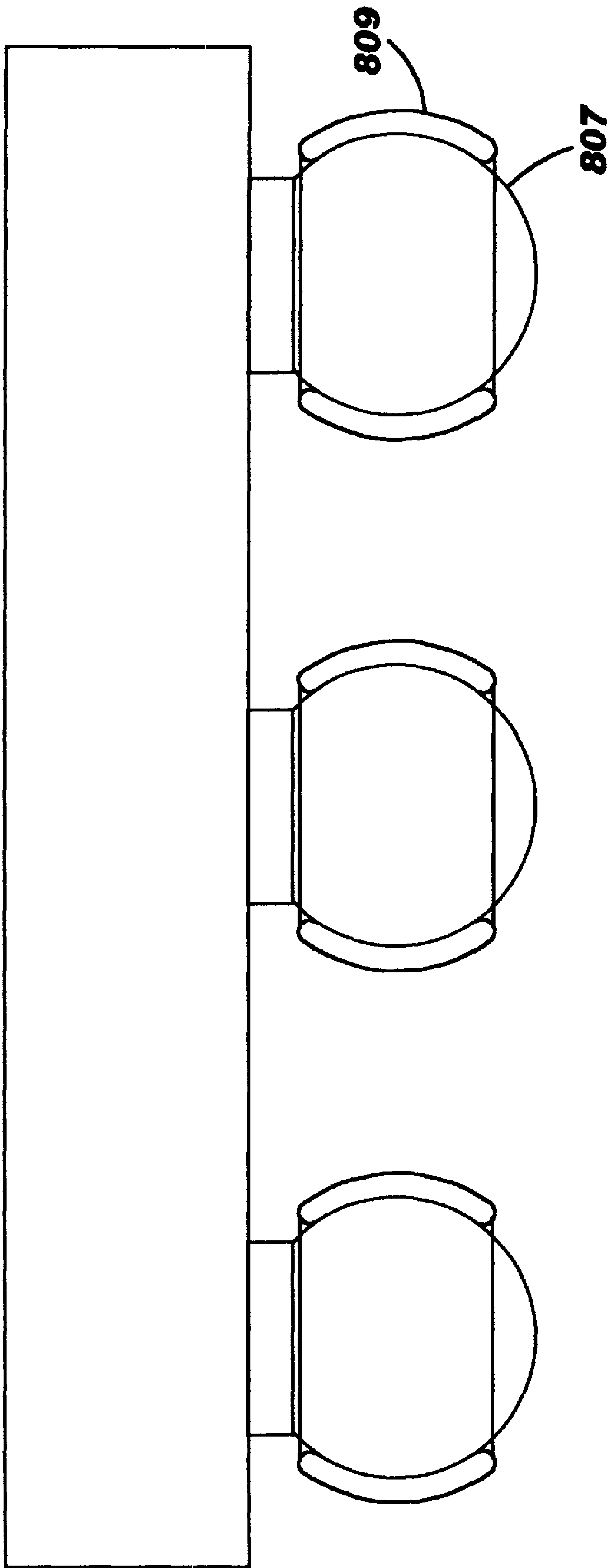


FIG. 8

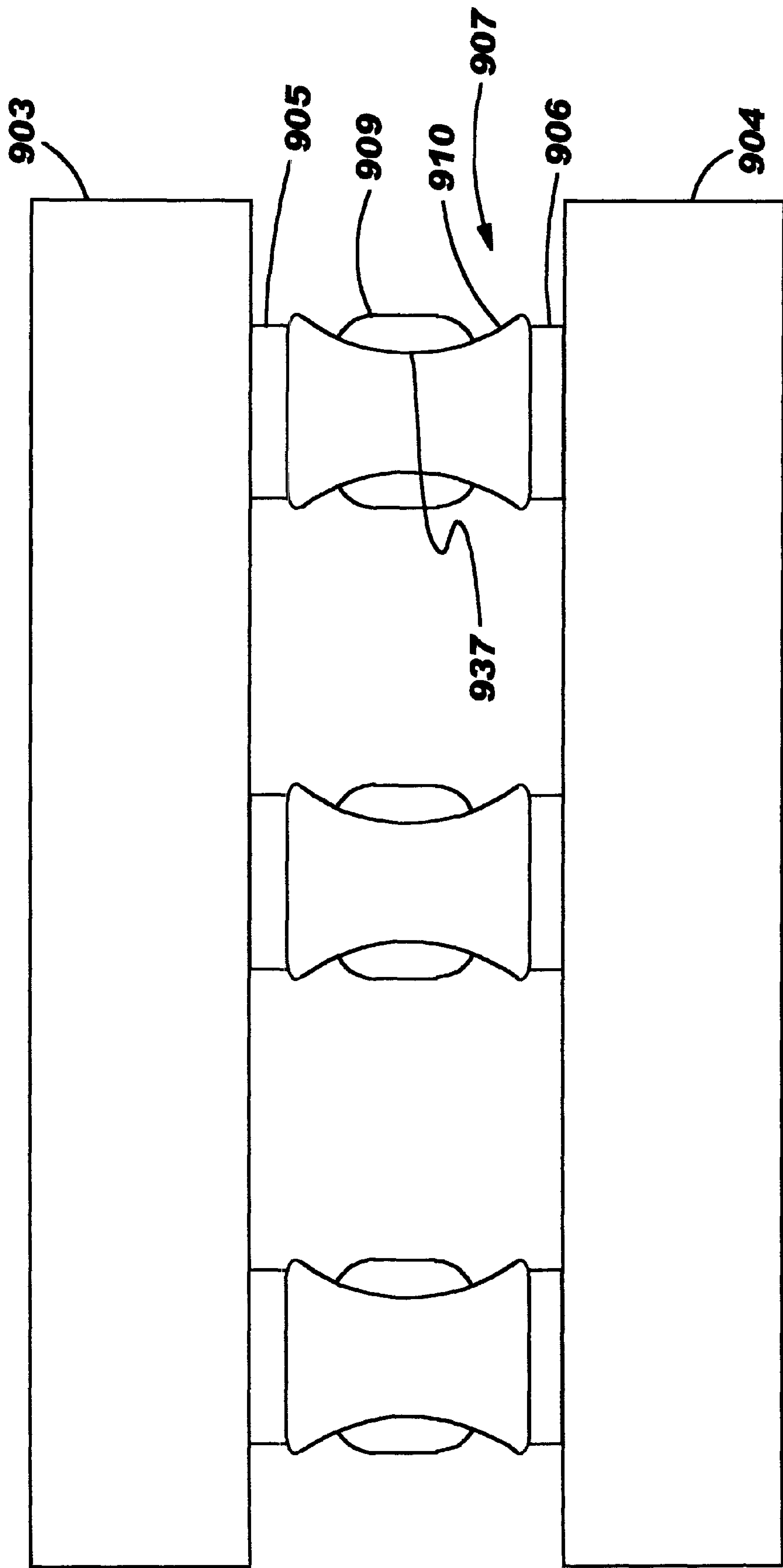


FIG. 9

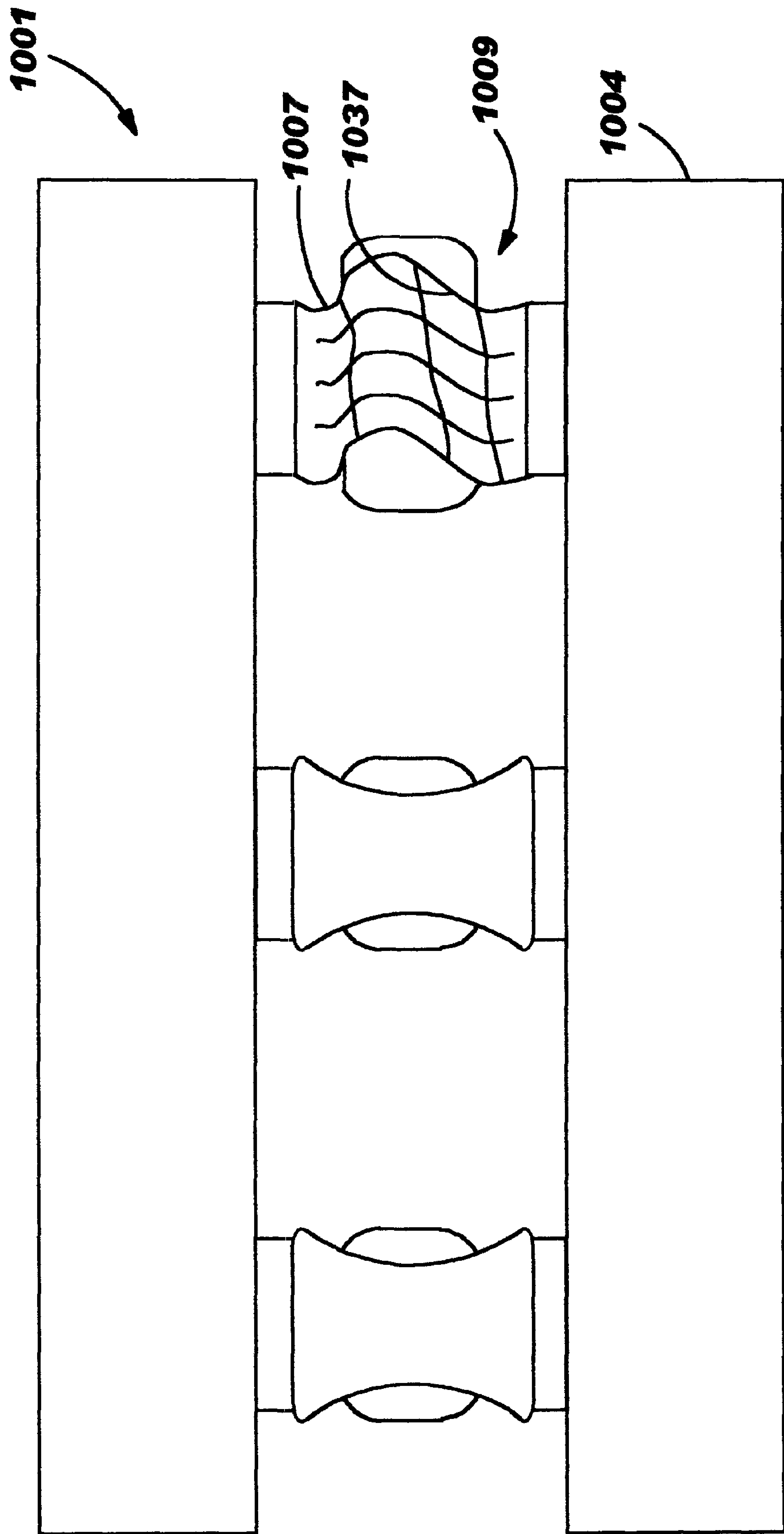


FIG. 10

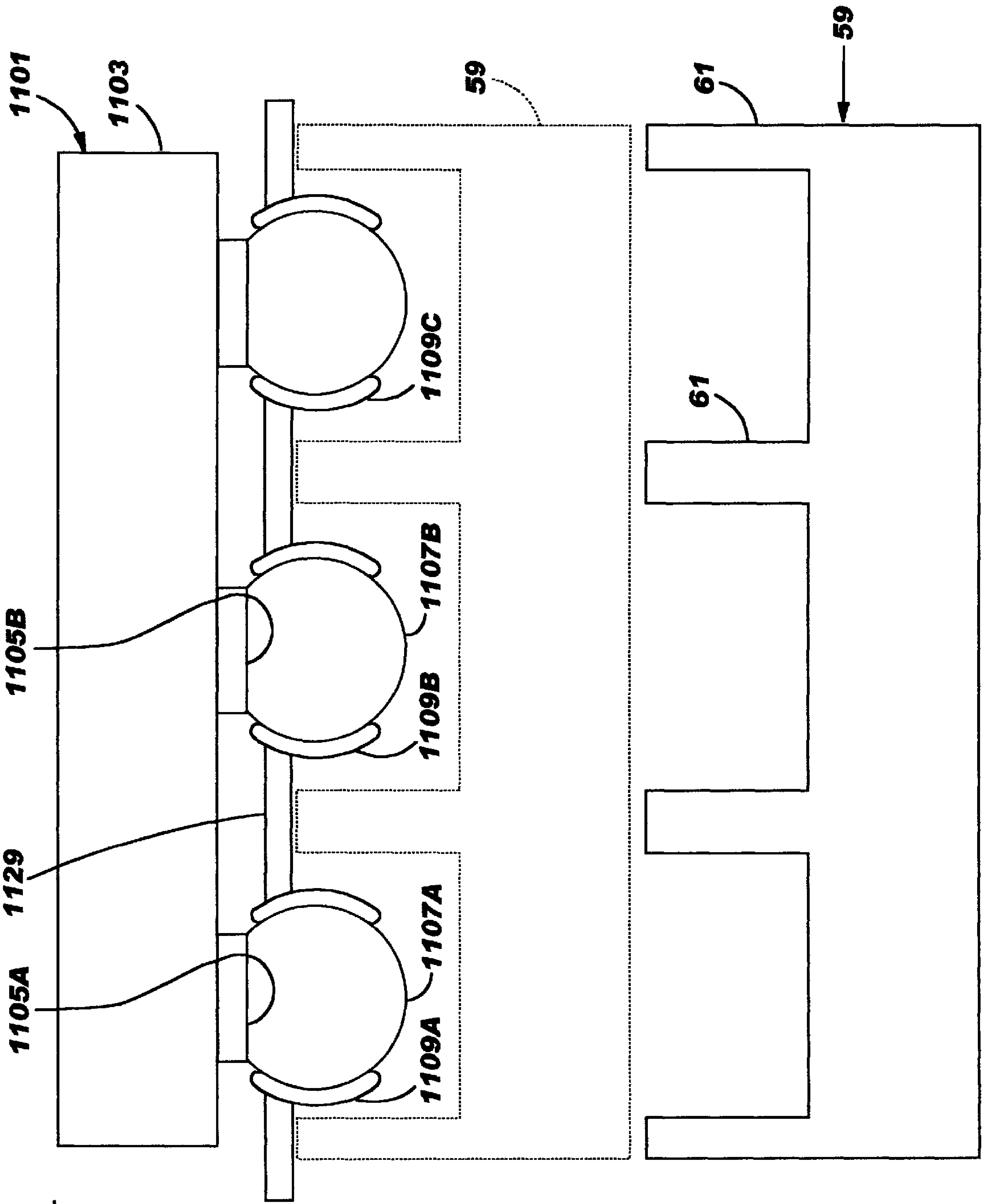


FIG. 11

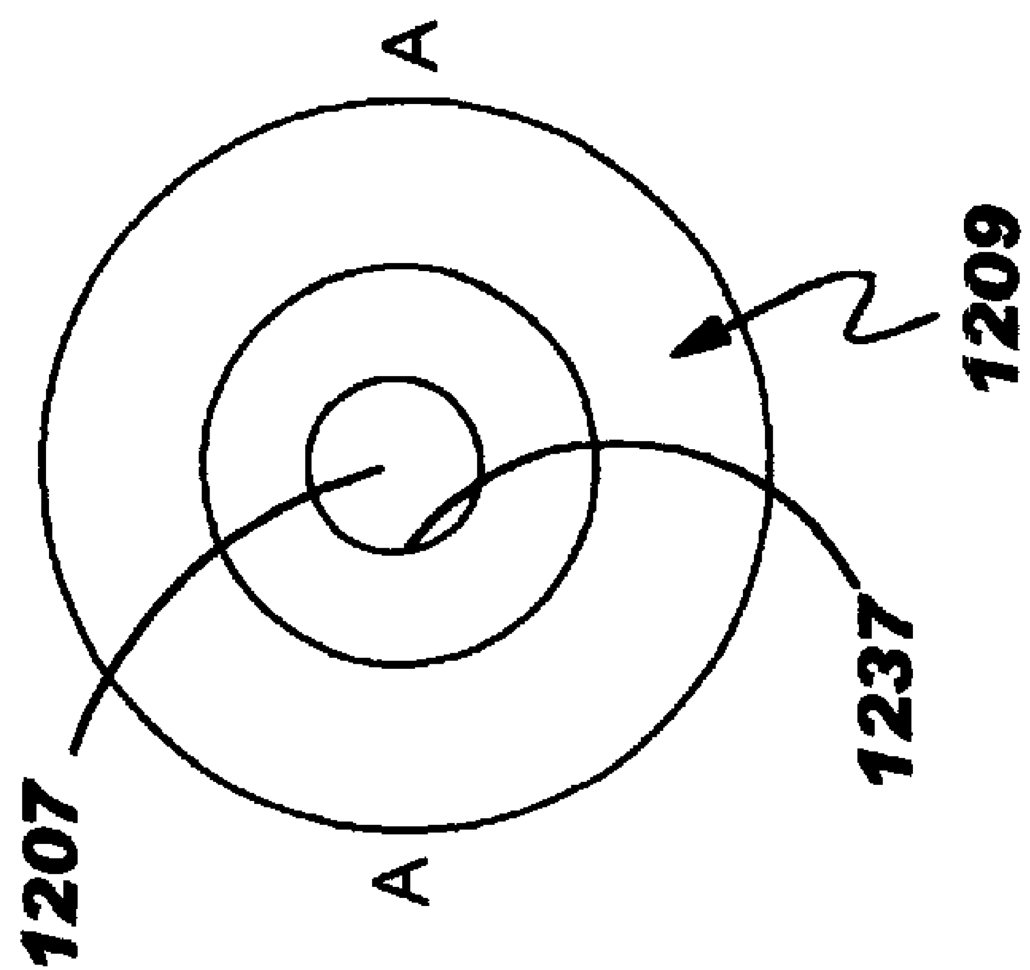


FIG. 12A

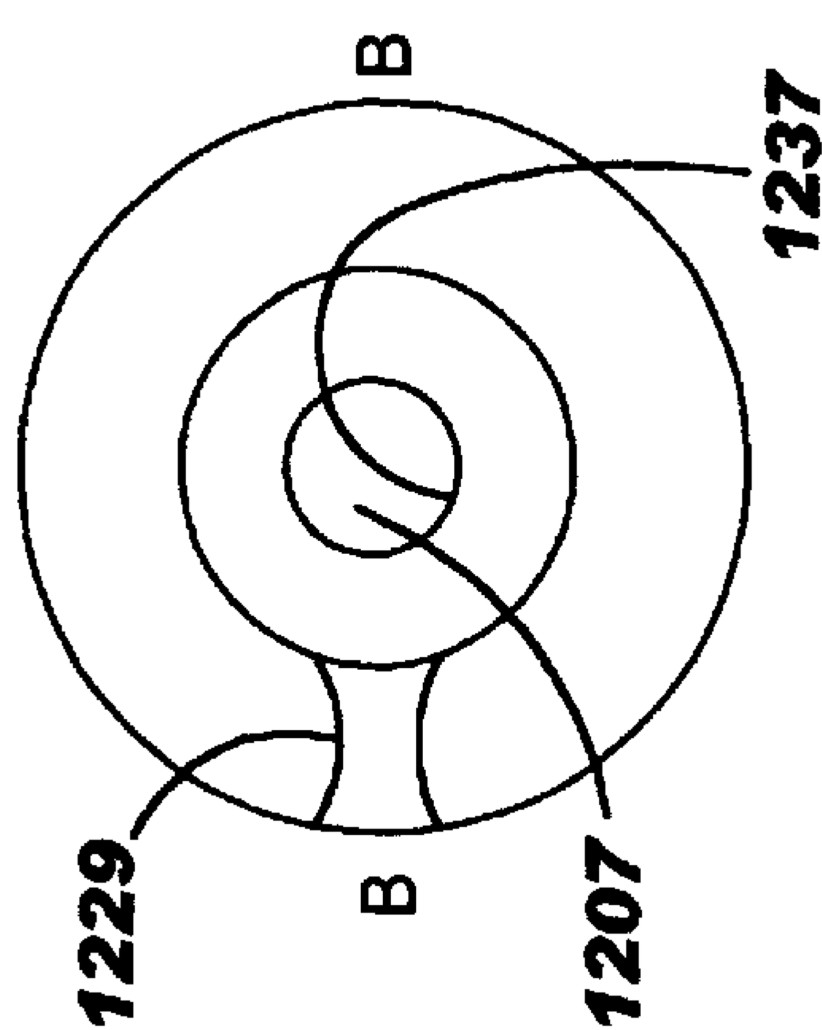


FIG. 12B

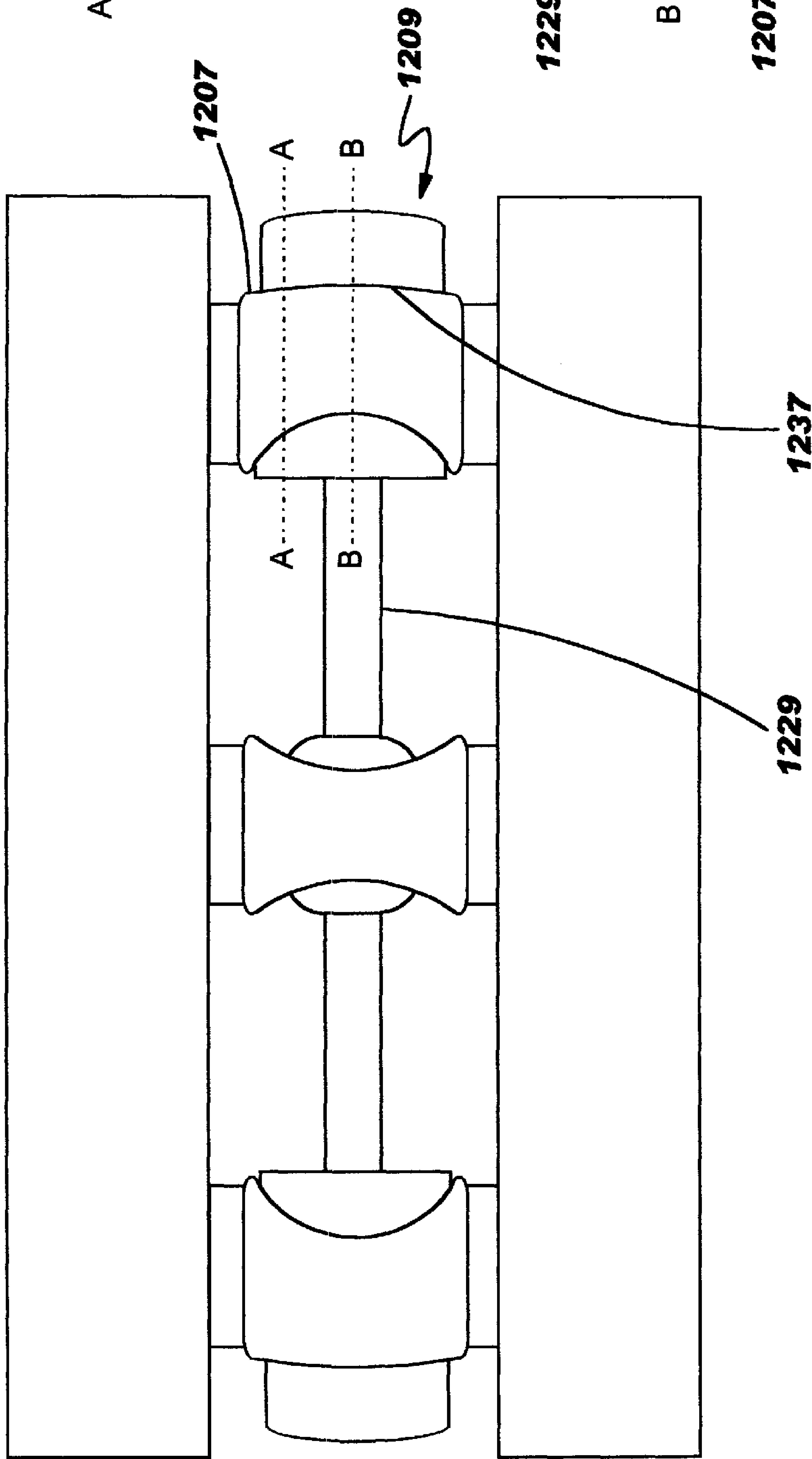


FIG. 12

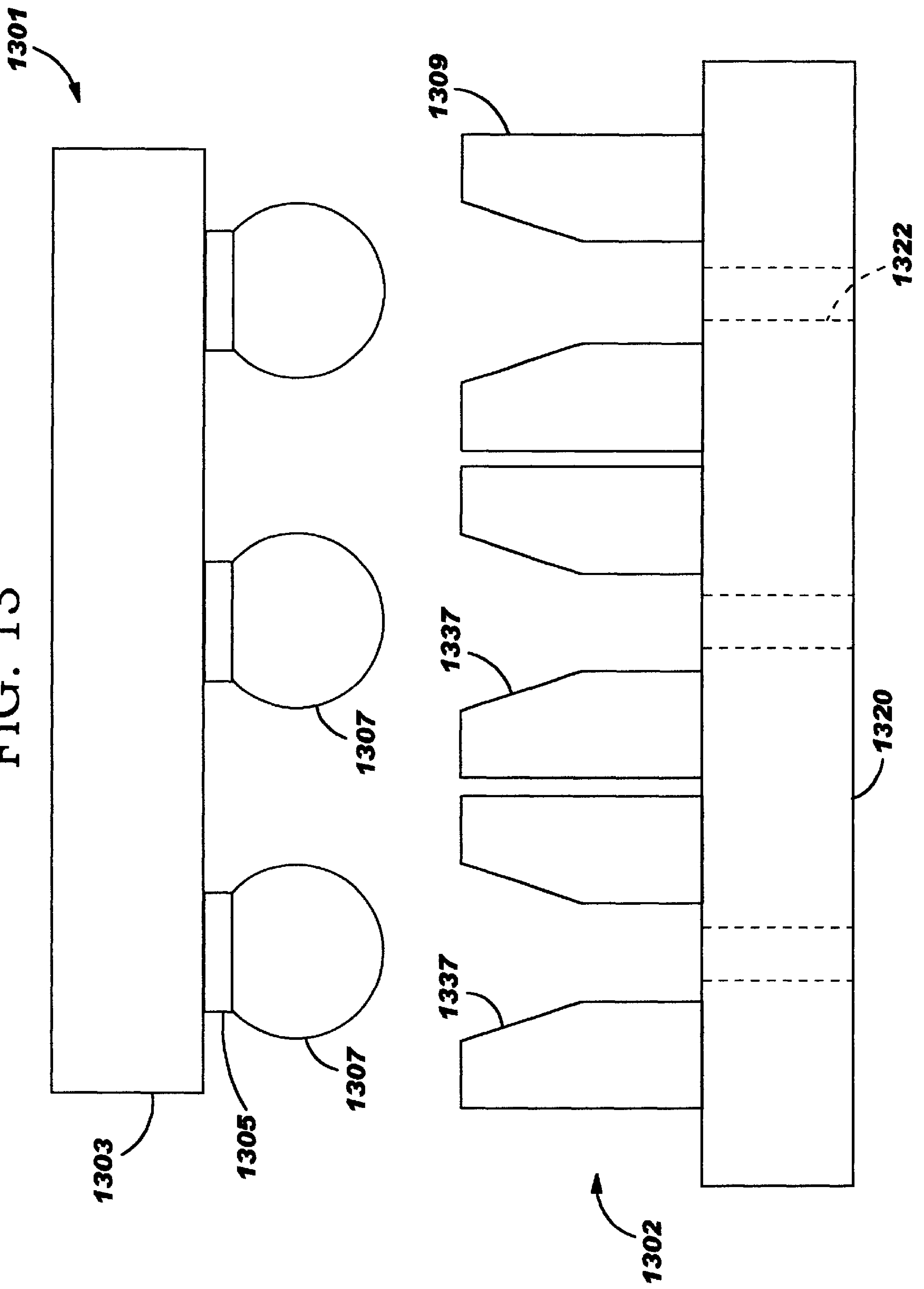


FIG. 13
1301
1309
1322
1337
1307
1320
1337
1307
1303
1305
1302

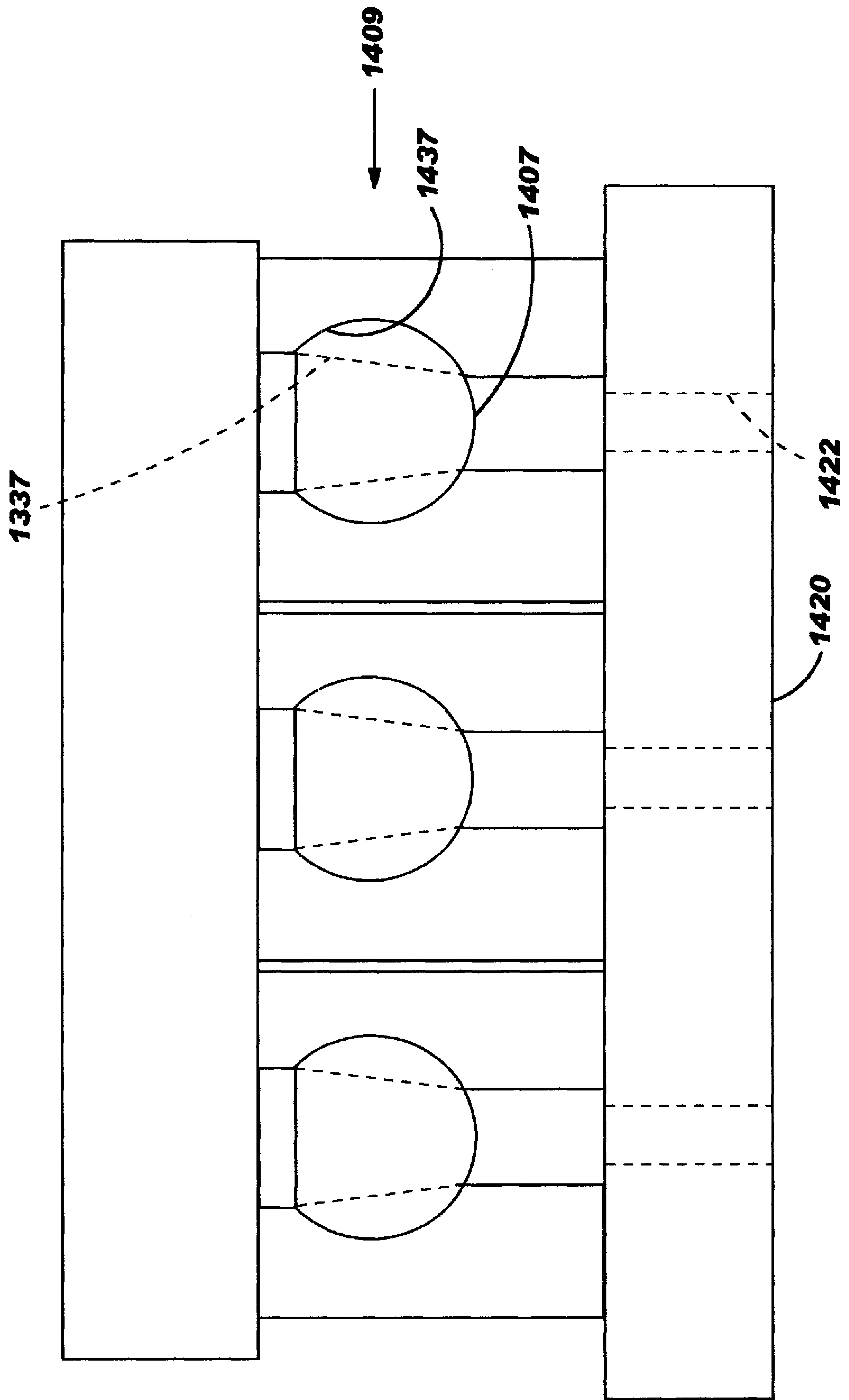


FIG. 14

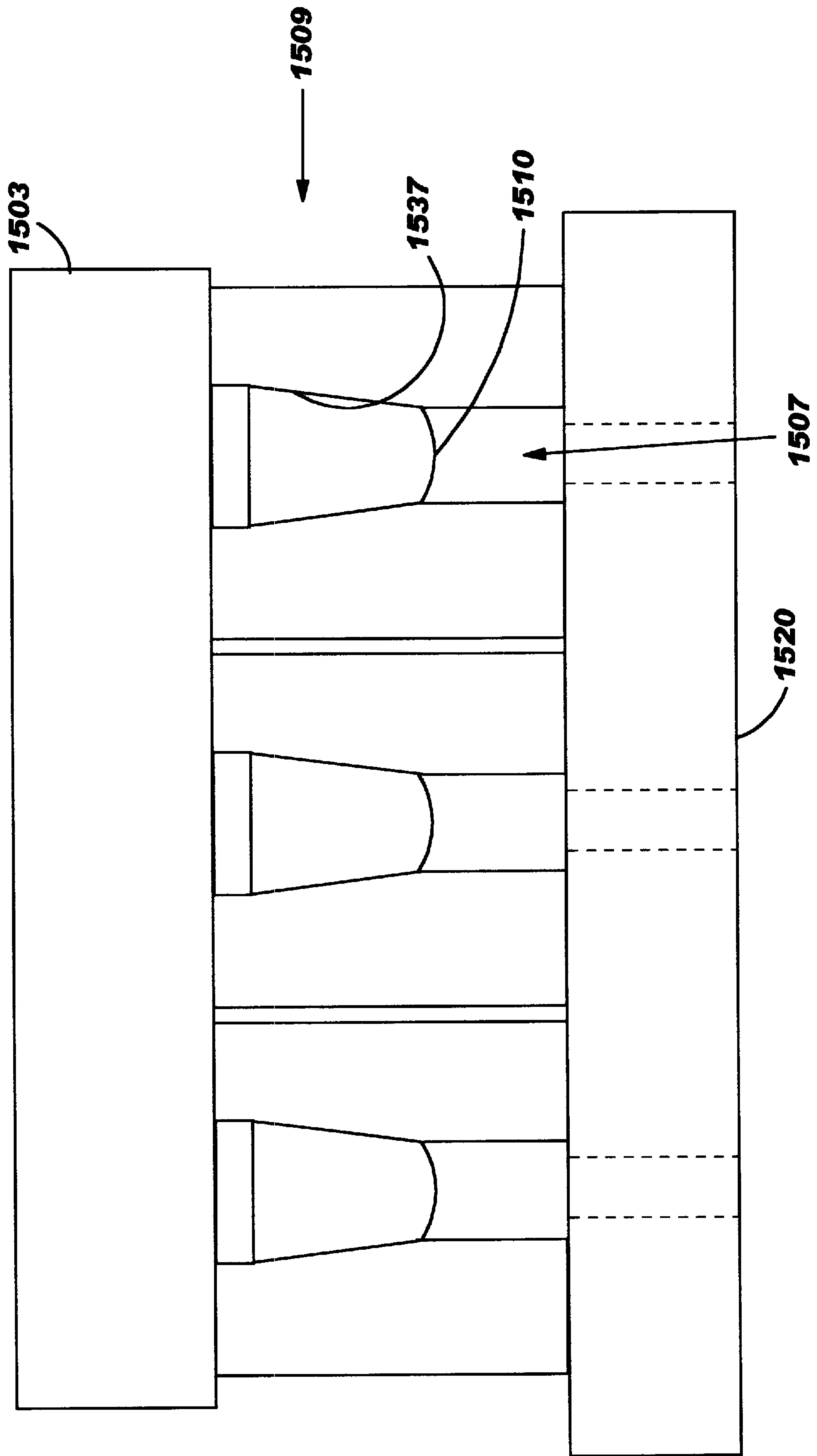


FIG. 15

1601
1603
1605
1607
1623
1625
1631
1621
1629
1653
A
A
1639
1609
1627
1609
1643
1645
1645
1649
1647

FIG. 16

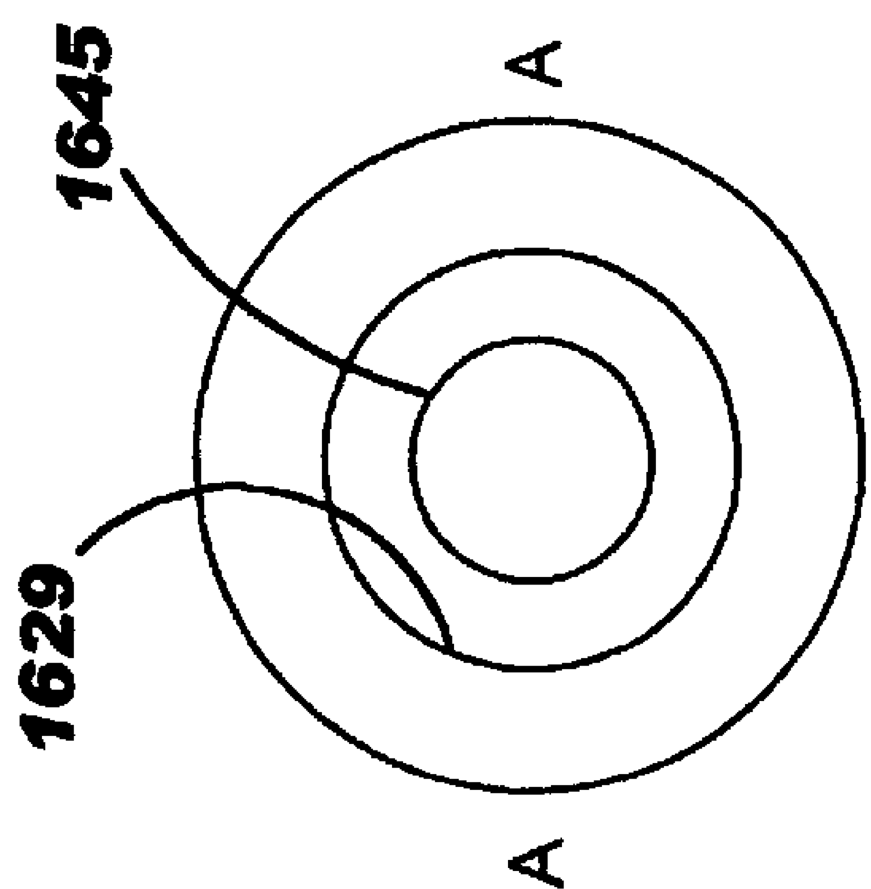


FIG. 16A

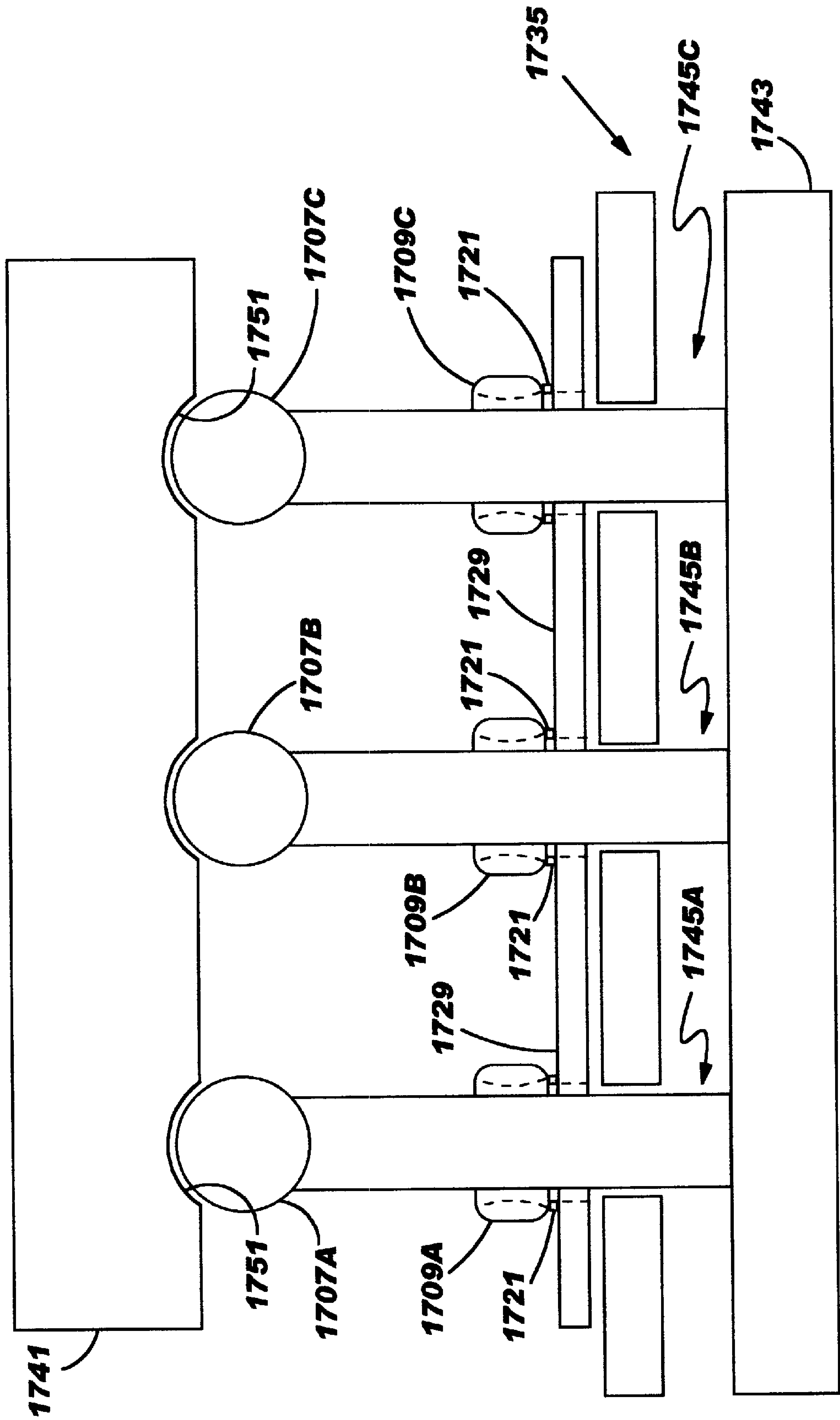


FIG. 17

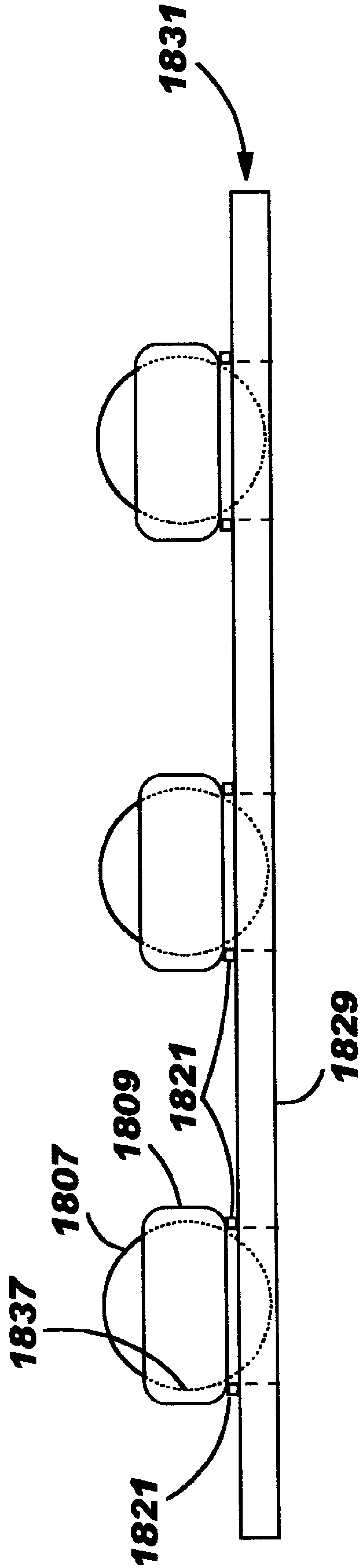


FIG. 18

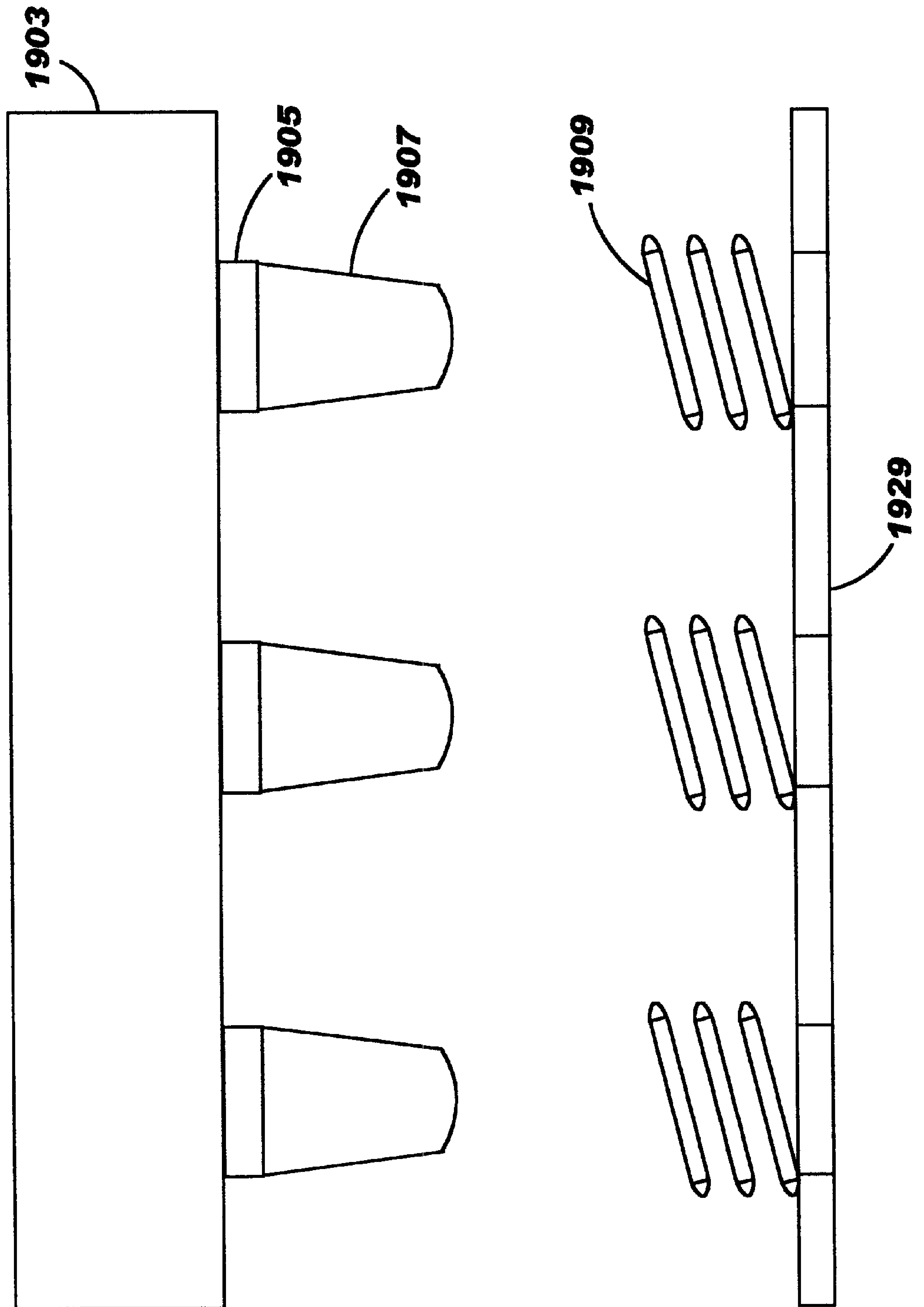


FIG. 19
1903
1905
1907
1909
1929

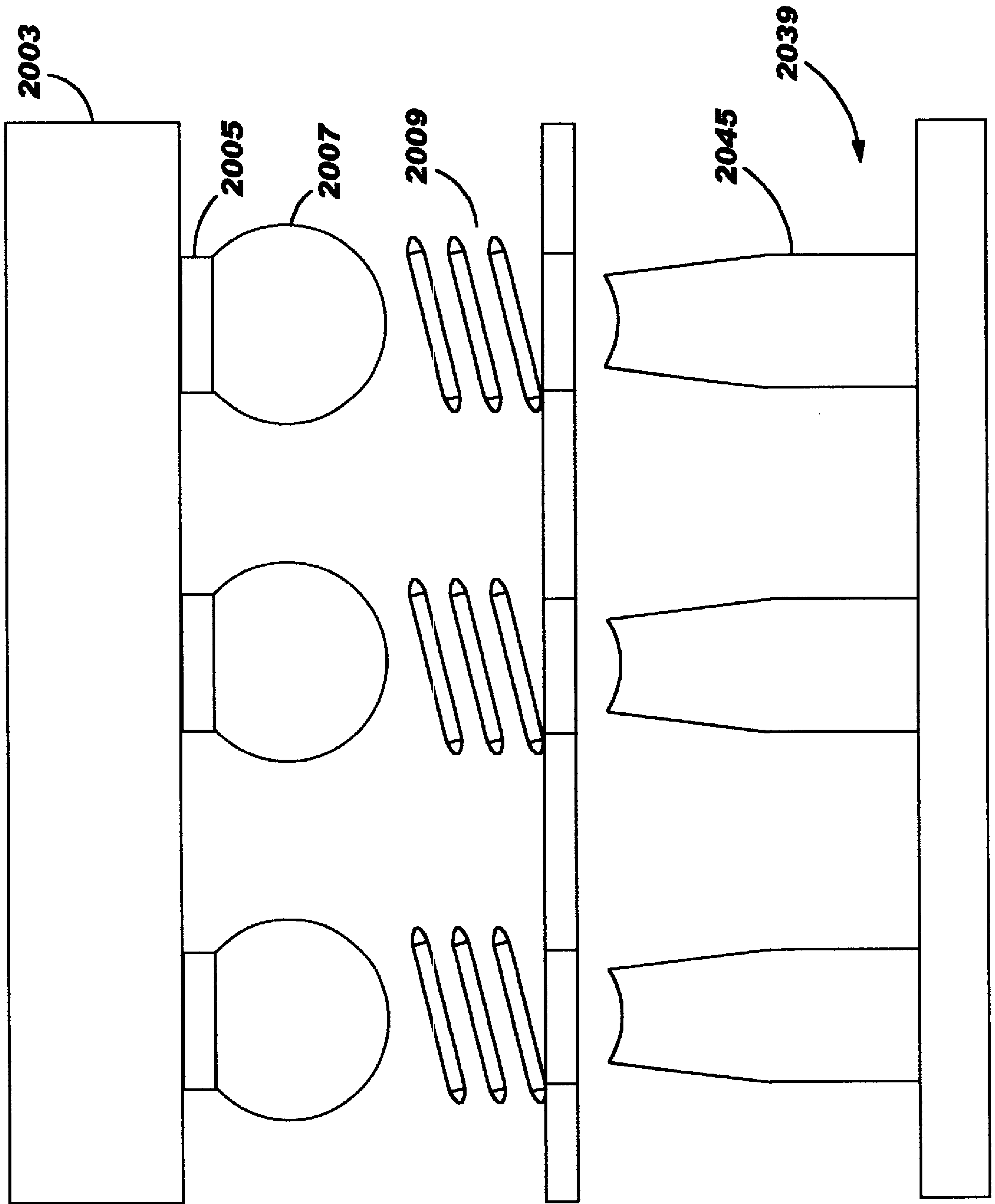


FIG. 20

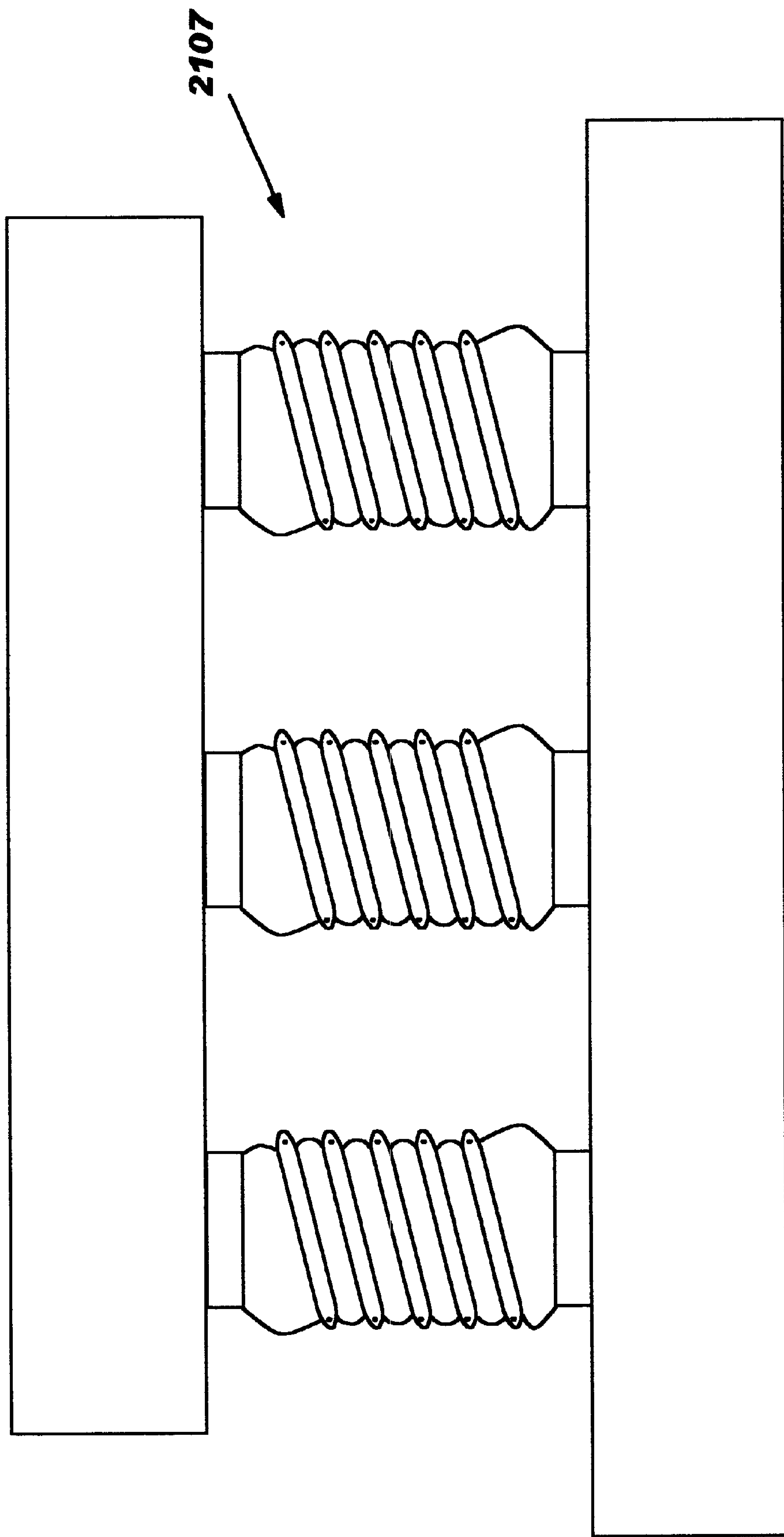


FIG. 21

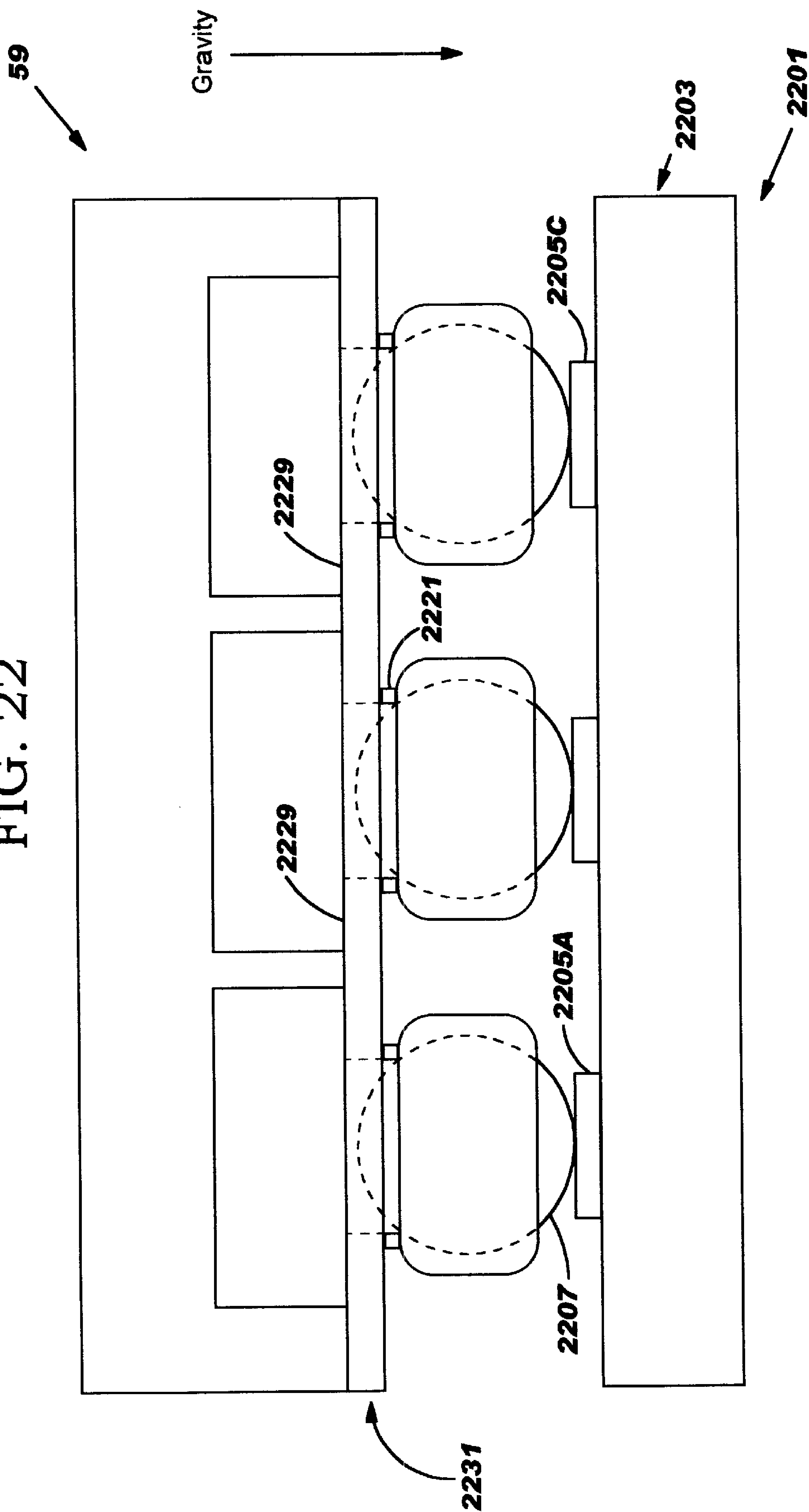


FIG. 22
Gravity
59
2201
2203
2205C
2229
2221
2229
2205A
2207
2231

METHOD OF REFORMING REFORMABLE MEMBERS OF AN ELECTRONIC PACKAGE AND THE RESULTANT ELECTRONIC PACKAGE

FIELD OF THE INVENTION

The invention relates generally to electronic packages and more particularly to assemblies for connection of integrated circuit chips to chip carriers, chip carriers to printed circuit boards, modules to printed circuit cards, and the like.

BACKGROUND OF THE INVENTION

Various ceramic ball grid array packages, leadless chip carriers, laminated chip carriers, tape ball grid array packages, and overmolded, globtop, and plastic ball grid array packages are known today. Such packages typically contain a semiconductor device (a chip) and provide for electrical and thermal connection paths to and from the chip, while protecting the chip from extraneous environmental factors, processing chemicals, and handling.

Such packages typically include connections known in the art as solder reflow (or melt) connections. These connections provide for both electrical and thermal conduction paths. It is known from prior art that a reformable solder ball **107** can be attached to contact pad **105** on substrate **103** of electronic package **101**, as depicted in FIG. **1**. Further, as depicted in FIG. **2**, it is known from prior art that solder ball **207** can be attached to contact pad **206** of substrate **204**. Typically substrate **204** is circuitized. Solder ball **207** provides a standoff distance s between contact pads **205** and **206**; this standoff provides mechanical compliance between the two substrates. It is also known that a higher standoff, with resulting increased compliance, can result in improved resistance to fatigue. The connections may be formed between a chip and a circuitized substrate, serving as a chip carrier package. Examples of circuitized substrates include printed wiring boards, flexible circuit cards, laminated chip carriers, metallized ceramic substrates, and multi-layer ceramic substrates. When a chip is connected to a circuitized substrate with numerous solder reflow connections, this form of connection is also known in the art as "flip-chip" or controlled collapse chip connection (C4), and results in a flip chip package.

Aside from flip chip packages, there are many kinds of chip carrier packages known in the art of semiconductor packaging. Other forms of chip carrier packages include wirebond chip carriers, thermo-compression bond chip carriers, and hybrid chip carrier devices. Further connection of a chip carrier package to a circuit card or board may be accomplished by utilizing known solder reflow methods to obtain what is commonly known as a ball grid array (BGA) connection therebetween. Various circuit cards, usually comprised of several layers of dielectric material, e.g., fiberglass-reinforced epoxy resin, interspersed with various conductor layers, (power, signal and/or ground planes) and often including plated through-holes and/or internal conductive vias, are known in the art.

An inherent problem with either the C**4** or BGA connection is that the thermal expansion characteristics of the two objects being connected may differ substantially. For example, the linearized coefficient of thermal expansion (CTE) of silicon is in the 2.5 to 4.0 part per million/degree Celsius (ppm/C.) range, while the CTE of a circuitized substrate may be 3 to 25 ppm/C., depending on the material choices. Therefore, the solder connections between a chip

and circuitized substrate will be subject to thermally-induced stresses. This stress is generally increased by the use of larger, more complex, higher performance (i.e., more powerful and thermally dissipative) and higher signal count chips. Since many hundreds, and even thousands, of connections may be present in a single chip carrier package, the method of forming the connections must also be reliable, manufacturable, efficient, and economical. In a similar manner, thermal expansion mismatch between a chip carrier package and a circuit card or board may give rise to significant stresses which adversely affect reliability. (A typical printed circuit board composed of common glass-epoxy has a CTE value of 17 to 22 ppm/C., while a chip carrier has a composite CTE value which may vary from 3 ppm/C. to 25 ppm/C., depending on geometry and material choices.)

To manage these problems, several strategies are known in the art. Two of these include the use of a stress-relieving underfill (or encapsulant), and the use of high-standoff solder joints including high-melt solder standoffs and solder-coated copper ball standoffs. The use of fatigue resistant solder materials, the use of conductive adhesives to form the C**4** or BGA connections, and the use of compliant substrate materials are also known in the art. Each of these methods helps to form reliable connections, but at a cost of manufacturability, restrictive material choice, or other disadvantage. For example, the use of underfill as a stress-relieving method to protect the connections generally prevents subsequent removal and replacement to replace or repair a device (commonly known as rework). The use of a solder-coated copper ball as a standoff-enhancement device results in a higher standoff, but greatly increased joint stiffness. Known solder columns comprise preformed high-temperature solder material. The high-temperature material is required to keep its preformed shape during subsequent solder reflow attachment. The solder column is generally attached to a device with a second, lower-melting solder in conjunction with an alignment fixture. The manufacturability difficulties of the solder column connection method limit the pitch (distance between adjacent columns) of a package interconnection to about 1.0 millimeter (mm) at the present time, and require the use of a hierarchy of solder melt materials.

A method for dynamically forming a solder column instead of preforming the solder column, while retaining a column-like shape during temperature excursions beyond the solder melt temperature would be very desirable. Further, the ability to obtain shapes other than simple columns would be very desirable because the shape of the solder connection can influence the internal stresses, and the reliability of the connection and manufacturability.

OBJECTS AND SUMMARY OF THE INVENTION

An object of the present invention is to provide an electronic package having an improved standoff capability to provide improved package reliability.

Another object of the present invention is to provide a fixture for preparing the foregoing electronic package for assembly manufacturing.

Still another object of the present invention is to provide a method for preparing the foregoing electronic package for manufacturing.

According to one aspect of the present invention, an electronic package is provided comprising a substrate having a contact pad thereon, a reformable member positioned

on the contact pad, and an elastic member positioned substantially around the reformable member.

According to another aspect of the present invention, there is provided an apparatus for positioning the elastic member, substantially around a reformable member with the reformable member positioned on a base. The apparatus comprises a first plate having a pin projecting into an opening of the elastic member and a second plate having an aperture therein and interposed between the first plate and the elastic member. The pin projects through the aperture in the second plate. The second plate is movably positioned with respect to the pin of the first plate for removing the elastic member from the pin and positioning the elastic member substantially around the reformable member such that the reformable member is located in the opening of the elastic member.

The invention is adaptable to mass production and will provide significant improvement in the ability to manufacture high reliability electronic packages, having a high standoff from the substrate to which the packages are assembled.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a partial side sectional view, in elevation and on a much enlarged scale, of an electronic package in accordance with prior art.

FIG. **2** is a partial side sectional view, in elevation and on a much enlarged scale, of the electronic package of FIG. **1** connected to a circuitized substrate in accordance with the prior art.

FIG. **3** is a partial side sectional view, in elevation and on a much enlarged scale, of an electronic package with a reformable solder ball positioned to receive an elastic sleeve in accordance with the present invention.

FIG. **4** is a partial side sectional view, in elevation and on a much enlarged scale, of the electronic package of FIG. **3** after the elastic sleeve has been positioned around the reformable solder ball.

FIG. **5** is a partial side sectional view, in elevation and on a much enlarged scale, of the electronic package of FIG. **4**, depicting the elastic member positioned around a reformed solder slug.

FIG. **6** is a partial side sectional view, in elevation and on a much enlarged scale, of an electronic package in accordance with another embodiment of the present invention, depicting elastic sleeves substantially surrounding reformable solder balls positioned near a circuitized substrate.

FIG. **7** is a partial side sectional view, in elevation and-on a much enlarge scale, of the electronic package of FIG. **6** after heating and in contact with the circuitized substrate after heating and contact.

FIG. **8** is a partial side sectional view, in elevation and on a much enlarged scale, of an electronic package in accordance with yet another embodiment of the present invention, depicting elastic sleeves substantially surrounding reformable solder balls.

FIG. **9** is a partial side sectional view, in elevation and on a much enlarged scale, of an electronic package in accordance with still another embodiment of the present invention depicting reformed solder slugs in a substantially hourglass shape.

FIG. **10** is a partial side sectional view, in elevation and on a much enlarged scale, of an electronic package in accordance with another embodiment of the present invention, depicting elastic sleeves substantially surrounding reformable solder columns.

FIG. **11** is a partial side sectional view, in elevation and on a much enlarged scale, of an electronic package in accordance with another embodiment of the present invention, depicting elastic sleeves substantially surrounding reformable solder balls.

FIG. **12** is a partial side sectional view, in elevation and on a much enlarged scale, of an electronic package in accordance with another embodiment of the present invention, depicting elastic sleeves substantially surrounding reformed c shaped solder slugs.

FIG. **13** is a partial side sectional view, in elevation and on a much enlarged scale, of an electronic package in accordance with another embodiment of the present invention, depicting an assembly of elastic sleeves for positioning over reformable solder balls.

FIG. **14** is a partial side sectional view, in elevation and on a much enlarged scale, of an electronic package in accordance with another embodiment of the present invention, depicting the assembly of elastic sleeves shown in FIG. **13** positioned over and around the reformable solder balls.

FIG. **15** is a partial side sectional view, in elevation and on a much enlarged scale, of an electronic package in accordance with another embodiment of the present invention, depicting the assembly of elastic sleeves of FIG. **13** positioned around reformable solder balls with reformable solder balls being shaped by elastic sleeves to form reformed solder slugs.

FIG. **16** is a partial side sectional view, in elevation and on a much enlarged scale, of an electronic package in accordance with still another embodiment of the present invention, depicting the reformed solder slugs shown in FIG. **15** after removal of the elastic sleeves. Also shown is an apparatus for further positioning other elastic sleeves on the reformed solder slugs.

FIG. **17** is a partial side view, in elevation and on a much enlarged scale, depicting an alignment fixture in accordance with the present invention for positioning elastic sleeves on reformable solder balls.

FIG. **18** is a partial side sectional view, in elevation and on a much enlarged scale, depicting elastic sleeves with a connector positioned on reformable solder balls in accordance with the present invention.

FIG. **19** is a partial side sectional view, in elevation and on a much enlarged scale, of an electronic package with several reformable solder slugs in accordance with still another embodiment of the present invention and an assembly of coiled elastic sleeves for positioning over the reformable solder slugs.

FIG. **20** is a partial side sectional view, in elevation and on a much enlarged scale, of an electronic package with several reformable solder balls in accordance with another embodiment of the present invention, depicting an assembly of coiled elastic sleeves and tapered pins for prestressing and positioning the elastic sleeves over the reformable solder balls.

FIG. **21** is a partial side sectional view, in elevation and on a much enlarged scale, of an electronic package with several reformed solder slugs in accordance with another embodiment of the invention and coiled elastic sleeves.

FIG. **22** is a partial side sectional view in elevation on a much enlarged scale depicting elastic sleeves with a connector positioned on reformable solder balls positioned on contact pads by the weight of a tool.

BEST MODE OF THE INVENTION

Referring now to the drawings in detail, FIGS. **3–5** illustrate a process for making an electronic package accord-

ing to one embodiment of the present invention. The electronic package **301** comprises a substrate **303**, a contact pad **305**, and a reformable ball **307**. By way of example, reformable ball **307** is a solder ball. An elastic sleeve **309** is formed from rubber, plastic or a shaped memory alloy and is initially apart from electronic package **301**. When relaxed, an inner diameter (shown in phantom) of elastic sleeve **309** is less than an outer diameter of reformable solder ball **307**. In FIG. **4**, elastic sleeve **309** has been positioned around reformable solder ball **307** by stretching the elastic sleeve from its relaxed state to an unrelaxed state conforming to the outside diameter of the reformable solder ball **307**. To ease application of the elastic sleeve, a lubricant such as a solder flux may be employed. A girdling (or squeezing) pressure now exists between elastic sleeve **309** and reformable solder ball **307**, while ball **307** is in a solid condition. By heating reformable solder ball **307** to its softening temperature, the solder ball responds to the girdling pressure exerted by elastic sleeve **309**. Consequently, reformable solder ball **307** takes a new elongated shape depicted in FIG. **5** as reformed, nipple-shaped solder **507**, which shape is predetermined and held by now-relieved elastic sleeve **309**. As seen in FIG. **4**, elastic member **409** contacts the side portion of reformable member **407** and not the bottom portion thereof. The bottom portion is, of course, the portion which is directly positioned on and electrically coupled to an external conductor (not shown). After reshaping, the stiffness of the reformed solder **507** may be increased by reducing temperature. In particular, an increased standoff distance h' between contact pad **305** and the tip of reformed solder **507** is evident (as compared to distance h in FIG. **3**).

The method for making and utilizing an elongated reformed slug may be varied somewhat depending on the materials chosen, so several examples will be given to illustrate how to best implement the present invention.

Softening of many materials such as plastics, epoxies, metals, and organic materials is known to occur at increased temperature. With some materials, such as solder, a phase change from solid to a melt or molten state of the material can be achieved at a sufficient temperature. The molten state exhibits essentially a zero shear modulus. Eutectic tin-lead solder, for example, has a melting phase transition point of about 183° C. (Centigrade). Higher melting point solders can be obtained with various ratios of tin and lead; about 3% tin and about 97% lead is a common high-melt (about 310° C.) alloy.

Numerous plastics exhibit a phase transition from hard, glass-like behavior to relatively soft, visco-elastic behavior at a temperature, known as the glass transition temperature, in the range of about −70° C. to about 170° C. and have a corresponding, approximately ten times decrease in stiffness through that transition. These materials when filled with conductive particles can be used as reformable balls or slugs in conjunction with appropriate choices of materials for elastic members. For example, epoxy resins, which can have electrically conductive filler particles such as silver mixed in with the resin can have glass transition temperatures below about 100° C.

The method of making electronic package **701** with a high standoff reformed slug **707**A illustrated in FIG. **7** will now be described. FIG. **6** illustrates an elastic sleeve **609**A which has been stretched onto and around reformable ball **607**A prior to any heat being applied. The final shape and diameter of the opening **737**A (FIG. **7**) of the elastic sleeve **609**A on reformed slug **707**A are carefully chosen and predetermined in conjunction with both the quantity of material in the reformable ball **607**A and the contact pad **605**A geometry, so as to obtain a desirable final shape of reformed slug **707**A. For example, for a circular contact pad with diameter of about 24 mils (thousandths of an inch), and a eutectic solder volume of 10000 cubic mils of solder, the cylindrical sleeve would have an interior diameter of about 22 to 23 mils, with a height of about 10–15 mils, and a wall thickness of about 2 to 4 mils. For this configuration, the maximum initial diameter of the reformable ball **607**A is about 28 mils, so that the elastic sleeve **609**A is circumferentially stretched to be positioned around reformable ball **607**A, applying pressure onto the reformable ball. When the reformable ball is comprised of eutectic solder, before the heat is applied, the pressure of the elastic sleeve **609**A has negligible effect on the shape of reformable solder ball **607**A. An excellent and common material choice for reformed slug **707**A is eutectic solder because it is both electrically and thermally conductive, has a relatively low melting point of about 183° C., has a high surface tension and easily wets to and connects to metallic contact pads **705**A and **706**A. In order to provide the high standoff of reformed slug **707**A with a minimum quantity of solder and small contact pad dimensions, elastic sleeve **609**A should be shaped as a hollow cylinder and comprise low durometer (less than about 70 Shore A) silicone rubber. Silicone rubber is resistant to high temperature (up to about 300° C. or more for short period of time, e.g., less than several minutes) without degradation. It also has desirable stiffness properties, because it is relatively soft (a modulus of a few hundred psi) compared to eutectic solder in solid phase (a modulus of about a million psi, depending on temperature) but is stiff compared to molten solder (with nearly a zero modulus, as it is a fluid). Other materials for the reformable slugs and elastic sleeves may be used as well. For example, soft plastic which shrinks upon heating may readily be obtained in the form of a cylindrical sleeve, and utilized to apply girdling pressure to a reformable slug in the form of a silver-filled conductive epoxy adhesive.

Reformable solder ball **607**A with elastic sleeve **609**A is positioned near another substrate **604** having contact pad **606**A, and the temperature of the reformable solder ball **607**A is increased to melt the reformable solder ball. The melting of the solder allows wetting of reformable solder ball **607**A to the second contact pad **706**A. The melting reduces the reformable solder ball **607**A material stiffness sufficiently so that the pressure exerted by elastic sleeve **609**A is sufficient to now force a changed shape, a cylinder depicted in FIG. **7** with opening **737**A. The girdling pressure exerted by elastic sleeve **609**A easily overcomes surface tension, and forces what would have been a truncated ball-like shape (as depicted in FIG. **2** of reformable ball **107**) into a more upright cylindrical shape **707**A. For the same quantity of solder and pad dimensions, a higher standoff height (s'>s) will result. The predetermined shape of the opening **737**A of elastic sleeve **709**A, as that of a cylinder, will nearly be replicated onto the molten reformed solder slug, as the resistance of the surface tension with respect to the material stiffness of the silicon rubber of elastic sleeve **709**A is very small. Portions **710**A of the surface of reformable slug **707**A which are not in contact with the elastic sleeve **709**A will take a rounded shape as dictated by surface tension. The transformation of shape occurs very quickly (on the order of seconds upon melting of the solder) and upon cooling, the transformed shapes are maintained. The elastic sleeve **709**A may be left in place, because the stiffness of the rubber comprising the elastic sleeve is small compared with solidified eutectic solder and no significant stress concentrations or detriments due to its presence will result.

However, there is a very significant fatigue life improvement realized for reformed slug **707**A due to the increased standoff, s', of the connection **702**. Even though the example presented here has described one attachment between substrates **603** and **604**, it can be easily shown that multiple attachments can be formed as shown in FIGS. **6** and **7**. For example, elastic sleeve **609**B acts to yield another elongated reformed slug **707**B which is positioned on contact pad **705**B of electronic component **701** and contact pad **706**B on substrate **704**. When there are multiple attachments on the electronic package, the present invention also reduces the tendency of reformable slug **707**A to accidentally contact and 'bridge' to another reformable slug **707**B to form an undesirable short circuit.

FIG. **9** illustrates another reformed solder slug **907** formed substantially in the shape of an hourglass in accordance with another embodiment of the present invention. FIG. **8** illustrates the manner of formation. An elastic donut-shaped sleeve **809** is stretched around reformable ball **807** which is attached to a contact pad **805** of a substrate **803**. Reformable ball **807** is initially in a solid form. Sleeve **809** provides a girdling pressure of approximately several pounds per square inch on the solder ball when the solder ball is in this solid, spherical form. The girdling pressure is not large, but is sufficient to reform the softened solder ball. Then, solder ball **807** is heated to its softening temperature and the elastic sleeve relaxes, forcing solder material outward from the interior of the sleeve. Portions **910** of reformed solder slug **907** which are not in contact with elastic sleeve **909** take a smoothed bulging shape.

The present invention allows electronic package designers to have many shape options available to optimize reliability of various electronic packages. Utilizing other shapes of openings of elastic sleeves to further tailor the resulting shape of the reformable ball or slug makes this possible. The elasticity of silicon rubber, approaching several hundred percent strain allows an elastic sleeve to be molded into a variety of complex and intricate shapes, even with substantially undercut features. In FIG. **10**, an example is depicted of an opening **1037** of elastic sleeve **1009** which has been used to form reformed slug **1007** into a shape resembling a helix. FIG. **10** illustrates three different cross sections of the sleeve **1009**. Other shapes are possible, for example, a C-shaped reformable slug **1209** is depicted in FIG. **12**. S-shaped, and even coil-shaped reformable slugs and many other useful shapes can be obtained with complementary elastic sleeve shapes.

A complex ball grid array electronic package may require several hundred or even several thousand successful electrical connections, but in some devices, e.g., ceramic substrate electronic packages, not all of the connection members are highly stressed during operation. Typically several dozen of the connections near the far corners are highly stressed, while the interior connections are not. The stress tolerant slugs of the present invention can be used on the highly stressed corner connections to relieve radially oriented shear stresses which result from thermal expansion mismatches in the electronic package. Shear and bending stresses within the connection member are driven by the radially oriented thermal expansion mismatches. Since shear and bending stresses within the connection member increase with member section thickness, it is clearly beneficial to reduce member section thickness. Member section thickness is defined as the diameter of a round connection member. However, it is only necessary to reduce member section thickness in one direction; that is, with respect to the radially oriented direction. A rectangularly or eliptically-sectioned hourglass shaped connection, with the thinnest bending axis (minor axis) oriented radially from the electrical package central point, substantially reduces shear stress for those connections. This configuration allows the connection member to have reduced stresses while retaining the greatest possible cross sectional area, so as to have the greatest possible tensile strength. The interior solder slugs do not need elastic sleeves surrounding them, because these solder slugs, when reformed will have increased standoff from standoff caused by the several dozen corner connections which have the elastic sleeves. In other words, not all of the package connections need to have an elastic sleeve on them to achieve the benefits of the present invention. Application of the elastic sleeves to a sufficient number of reformable slugs to overcome surface tension of all the slugs will create increased standoff for all. It is also possible to use the elastic sleeves to simply enhance standoff and not for electrical or thermal connection, by strategically placing reformable balls or slugs to uniformly "lift" the substrate.

Composite molding many elastic sleeves together with an internal alignment web as one part is most convenient and efficient to quickly and simply position thousands of elastic sleeves in one operation. In FIG. **11**, an elastic sleeve **1109**A is positioned around reformable ball **1107**A on contact pad **1105**A on substrate **1103**. Another elastic sleeve **1109**B is shown similarly positioned around another reformable ball **1107**B which is on another contact pad **1105**B on substrate **1103** of electronic package **1101**. The elastic sleeves **1109**A,B are connected together by web portion **1129**, which aligns the sleeves with the reformable balls on substrate **1103**. Positioning tool **59** (shown in two positions) with projections **61** has been used to press and position elastic members **1109**A,B and other elastic sleeves **1109**C, etc.onto and around reformable balls **1107**A,B etc. Since the elastic sleeve openings are molded in predetermined locations so as to align to and correspond to selected ones of reformable balls, it is a simple and expedient matter to press the composite mold into place.

FIGS. **13** through **15** illustrate another embodiment of the present invention, an assembly **1302** of elastic sleeves **1309** and base plate **1320** for positioning the sleeves over reformable balls **1307**. A portion of assembly **1302** can be positioned onto and around reformable balls **1307**. Openings **1337** of the sleeves are aligned with reformable balls **1307** on contact pads **1305** on substrate **1303** of electronic package **1301**. It is possible to have variously shaped and oriented openings **1337** in the sleeves, so that the shapes of reformable slugs on the electronic package are optimized for the best reliability of the electronic package attachment. One material that can be used for the sleeves is silicon rubber. The base plate **1320** secures the sleeves in place and can be comprised of a metal, preferably copper. Base plate **1320** includes pressure relief openings **1322** depicted as holes through the base plate **1320** to each opening **1337**.

In FIG. **14**, the openings **1337** (shown in phantom) of the sleeves of assembly **1309** are now positioned around respective reformable balls **1307**, with opening **1337** now stretched to larger opening **1437**, prior to softening of reformable balls **1307**. In FIG. **15**, reformed slug **1507** is formed by softening of reformable ball **1307** so as to yield to girdling pressure exerted by elastic sleeves **1337**. Opening shape **1537** is forced upon reformed slug **1507**. Portions **1510** of the elastic sleeves, not in contact with elastic sleeve, take a rounded shape as dictated by the surface tension of the softened material of reformed slug **1507**. This configuration is held until reformed slug **1507** is re-hardened, preferably by cooling. In FIG. **16**, the resulting electronic package **1601** is depicted with the reformed slug **1507** after assembly **1309** is removed.

Apparatus **1639** can provide for alignment and easy positioning of elastic sleeves **1609**. This apparatus includes a rigid first plate **1643** which aligns and holds a number of pins **1645**. These pins are positioned to corresponded to positions of respective reformed slugs **1507** which are positioned on contact pads **1305** on substrate **1303** of an electronic package **1601**. The elastic sleeves **1609** are loaded onto the pins, which then provide alignment and guidance, and are pressed onto and around corresponding reformed slugs. A connector web or sheet **1629**, depicted in phantom, is sheared off at tearaway tabs **1621**, leaving separated elastic sleeves **1609** on the pins. Plate **1639** is used to push and dispense the elastic sleeves **1609**. A second plate **1639** has apertures **1649** through which the pins **1645** extend, and is moveable so that second plate **1639** can force the elastic sleeves **1609** out and around the reformed slugs. The second plate **1639** is removed after the elastic sleeves are in position. Each of pins **1645** can be coated with a region **1653** of low-friction material, preferably Teflon (Teflon is a registered trademark of E.I. Dupont de Nemours and Co.) but alternately solder flux, plastic, or other low friction material can be used. Numerous elastic sleeves can be molded together as a one-piece part, with connector **1629** providing alignment between one another. When a reformable slug is shaped as a tapered cone, as reformed slug **1507**, there will be little stretching, and little stress in the elastic sleeve. Upon temperature induced melting, the solder slug will assume the same final shape of the reformed slug **907** shown in FIG. **9**. It is important that the reformable slug wet to the contact pad **906** before the elastic sleeve releases any stored stress, otherwise undesirable geometries may occur. A quantity of lower-melting solder paste or other adhesive may be used to provide sufficient wetting contact at the contact pad **906**.

For some applications, reformable balls which are not initially bonded to contact pads can be shaped with elastic sleeves according to the present invention. For example, if the reformable balls are made of a material having little surface tension or are difficult or impossible to adhere to an electronic package, reformable balls can be formed into desired shapes independent from the electronic package. In this case, a removable anisotropically conductive interposer may be needed. This is useful for various chip and wafer testing procedures. One example of this type of processing is illustrated in FIGS. **17** and **18**. In FIG. **17**, reformable balls are positioned on a base **1741**, with an alignment fixture **1735** in conjunction with a connector **1729** which interconnects elastic sleeves **1709**A, B and C. The connector **1729** remains connected to the elastic sleeves as the elastic sleeves **1709**A,B, and C are pressed onto and around the reformable balls **1707**A, B and C respectively. A base **1741**, with recesses **1751**, provides for alignment of the reformable balls and is used in conjunction with a series of pins **1745**A, B and C which are held and located by a first plate **1743**. As shown in FIG. **18**, elastic sleeves **1709**A, B and C have been positioned around reformable balls **1707**A, B, and C, using the alignment fixture **1735**, with the elastic sleeves being individually circumferentially stretched around the reformable balls. The girdling pressure provides friction which holds the reformable balls in place. The openings **1837**A,B and C of the elastic sleeves **1709**A,B and C conform to a rounded, ball-like reformable ball shape to provide retention force. In this prestressed, aligned state, a large sheet of an array of reformable balls may be easily handled, stored, transported, positioned, protected, inspected, and tested. Reformable balls may be removed, replaced as necessary, and prepared for use in joining an electronic package to another substrate. In many electronic packages, the 'pitch', or distance between one reformable ball to another is a constant (typically about 1.27 mm or about 1.00 mm for ball grid array packages) and the pattern of the placement of the balls is a simple square array. For these packages, which account for a large percentage of applications, it is possible to prepare large sheets of elastic sleeves with reformable balls pre-loaded. The desired quantity and size of reformable balls may simply be cut from the sheet as needed for various sized packaging applications. In this manner, the elastic sleeves connected by connector **1729** also become a useful packaging method for handling and transporting large numbers of reformable balls. A roll-like continuous process may be implemented to manufacture, store large quantities economically. The material chosen for the elastic sleeve, preferably cured silicon rubber, can maintain the circumferential prestress for a long period of time.

Connecting the sheet of reformable balls to an electronic package may be accomplished in one of two manners, depending on whether or not the connector **1729** is to remain in place in the final configuration. If it is desirable to remove the connector, the sheet of reformable balls with elastic sleeves attached may be positioned on contact pads **2205**A, B and C of an electronic component **2203** and heated so as to melt the reformable balls releasing the elastic sleeve prestress. To avoid having surface tension push the elastic sleeves away from the component, tool **59** may be used in conjunction with gravity weight as shown in FIG. **22** to be certain that elastic sleeve will remain in place and provide enhanced standoff as described earlier. Subsequently, the connector **2229** may be removed by shearing it off at tearaway features **2221**. The electronic package is then reflowed to another substrate with the elastic sleeves left in place to provide enhanced standoff and shape control.

In some applications there is no need to remove the connector between elastic sleeves. To avoid surface tension pushing the elastic sleeves out of place, it is necessary to make wetting contact between each of the contact pads on the electronic package and the reformable balls before elastic stress stored in the elastic sleeves is released, i.e., before the reformable balls are molten. This is simply accomplished by the use of a quantity of lower temperature melting material which is adhered or wetted to each reformable ball and each contact pad using, for example, a lower-melting solder paste in conjunction with application methods well-known in the industry (i.e. stencil applications). The solder paste may be rapidly applied to the one or both sides of each reformable ball while held in the sheet format.

If the reformable ball is chosen to be of a higher-melting temperature solder than the solder paste, the elastic sleeve, left in place, can serve as a protective barrier in conjunction with the shaping purpose of the present invention. For example, if a high-tin content solder paste (e.g., a eutectic paste) is used on the side of the reformable ball opposite the contact pad of an electronic component for attachment purposes, it may be desirable to maintain separation of the tin from the electronic component and the solder paste on the contact pad. Tin is metallurgically active with various other metals, and can rapidly attack and alter contact pad metallurgy and so form undesirable reaction byproducts. The elastic sleeve of the invention will prevent tin from wetting up the reformable ball during reflow and consequently will prevent the reactive tin attack on the contact pad of the electronic component. In a similar manner, silver, corrosive flux, or other harmful chemicals may be prevented from migration across the protective barrier formed by the elastic sleeve.

The present invention may also be utilized to form reformable slugs in the shape of a cone or cylinder. If the

reformable slugs are made of high-melt solder, it is possible to simply leave the cone or cylindrical shapes in place on the electrical component, making use of eutectic solder paste or lower melting point solder to effect an electrical connection. A distinct advantage of the invention over prior art methods of casting or molding is that undercut features, such as hourglass shapes, may be readily produced on reformable slugs. Hourglass shapes are known to have more optimal shear stress distribution characteristics than cylinders, cones, or balls.

A coil of soft aluminum wire, coated with polyimide or other material to which the reformable slug will not wet, may also be used as an elastic sleeve as depicted in FIG. **19**. The coil **1909** is slipped into place over a tapered reformable slug **1907** and connector **1929** is removed. A coil of a shape memory alloy wire can also be utilized as elastic sleeve **2009**, as illustrated in FIG. **20**. A shape memory alloy is a material exhibiting the characteristic of being able to return to a particular shape, despite significant deformations, upon heating to a temperature above a critical range known as an memory activation temperature range. Known materials which exhibit this characteristic include nickel-titanium alloys. There is some hysteresis involved in the actual deformation and shape return paths followed, over a range of temperatures spanning about 20° C. to about 60° C. but essentially the original shape is recovered by heating. The memory activation temperature range which activates the material microstructural changes and cause the recovery (which typically spans just a few degrees C.) of the material to its original shape may be tailored to be in a desired range by choice of alloy constituents of the material. A memory activation temperature range of about −100° C. to about +100° C. is available with known nickel-titanium materials, and deformations from the original shape involving material strains up to about 6 or 8 percent are possible to recover from. The wire may be coated with a material to prevent wetting of molten material of the reformable ball or slug. For example, a polyimide coating would prevent eutectic solder from wetting to it. A wire of this material may be formed into a coil by wrapping about a mandrel and held there while annealed (typically at about 400° C. to about 500° C. for a few minutes) so as to become 'memorized' as the 'original' or ground state for the material. The dimensions of this ground state are carefully chosen in conjunction with the quantity of material used for the reformable ball or slug and the desired final dimensions of the transformed shape of the reformed slug. Then, the coil, which comprises the elastic sleeve **2009**, may be stretched and deformed so as to have a greater diameter than the reformable ball or slug. As shown in FIG. **20**, tapered pins **2045** can be used to accomplish this. The prestretched elastic sleeve is then positioned around the reformable ball or slug. The wire and reformable ball or slug are then heated to a temperature which activates the shape memory alloy to constrict around the reformable ball or slug and squeeze it into a useful shape. Use of a coil wound one or more times around a reformable slug or ball can result in high aspect ratio shapes **2107**, as depicted in FIG. **21**. A coil with a memorized shape which is not of a uniform diameter may also be used, to create a reformable slug shape which is more useful (e.g., an hourglass shape). After memory activation, the shape memory alloy acts as a 'normal' material with a stiffness of about 5 Mpsi (million pounds per square inch) and CTE of about 6 to 11 ppm/C. A wire diameter of about 1 to about 3 mils coiled into a nominal diameter of about 10 to about 28 mils may typically be utilized in conjunction with contact pads of about 10 to about 30 mils diameter. In a manner similar to as described earilier, more than one elastic sleeve may be connected with a connector such as a sheet of water soluable paper or removable film of plastic.

Based on the foregoing, apparatus and methods for forming high stand-off or stress accommodating interconnect slugs have been disclosed. However, numerous modifications and variations may be provided without deviating from the scope of the present invention. For example various materials for reformable member, elastic member, or other portions of the invention may be substituted; shape designs may be changed so as to optimize results for specific electronic package needs; and methods may be combined and/or sequentially employed so as to form usefully shaped reformable connection members. Therefore the invention has been disclosed by way of illustration and not limitation, and reference should be made to the following claims to determine the scope of the present invention.

We claim:

1. An electronic package comprising:

a substrate having a contact pad thereon;

a reformable member having at least one side portion and a bottom portion positioned on said contact pad, said bottom portion adapte or being positioned on and electrically coupled to an external conductor; and

an elastic member positioned substantially around only said at least one side portion and in contact with said reformable member, said elastic member providing a girdling pressure on said reformable member.

2. The electronic package of claim **1** wherein said substrate comprises silicon or silicon-germanium.

3. The electronic package of claim **2** wherein said substrate is an integrated circuit.

4. The electronic package of claim **1** wherein said substrate comprises ceramic, epoxy, epoxy-glass, Teflon, polyimide, alumina, glass-ceramic, Kevlar, liquid crystal polymer, glass, fiberglass, or plastic.

5. The electronic package of claim **1** wherein said substrate is a chip carrier.

6. The electronic package of claim **1** wherein said substrate is a circuit card.

7. The electronic package of claim **1** wherein said reformable member is bonded to said contact pad.

8. The electronic package of claim **1** wherein said reformable member is electrically conductive.

9. The electronic package of claim **1** wherein said reformable member comprises solder.

10. The electronic package of claim **1** wherein said reformable member comprises a material selected from the group consisting of electrically conductive epoxy, silver, gold, tin, lead, bismuth, aluminum and copper.

11. The electronic package of claim **1** wherein said reformable member comprises a thermally dependent material.

12. The electronic package of claim **11** wherein said thermally dependent material has transition temperature in a range of about 40° C. to about 340° Centigrade.

13. The electronic package of claim **1** wherein said reformable member is substantially in a shape of an hourglass, a cylinder, a cone, or a nipple.

14. The electronic package of claim **1** wherein said elastic member comprises an elastic collar that surrounds only said at least one side portion of said reformable member.

15. The electronic package of claim **1** wherein said elastic member comprises rubber, plastic, or a shape memory alloy.

16. The electronic package of claim **15** wherein said elastic member generally has a shape of a doughnut, a sleeve, or a coil.

17. The electronic package of claim **15** wherein said rubber comprises silicone rubber.

18. The electronic package of claim **15** wherein said plastic comprises a thermally activated shrinking plastic.

19. The electronic package of claim **18** wherein said thermally activated shrinking plastic has an activation temperature in a range of about 40° to about 340° Centigrade.

20. The electronic package of claim **15** wherein said shape memory alloy has a memory activation temperature in a range of about 40° Centigrade to about 340° Centigrade.

21. The electronic package of claim **1** wherein said elastic member comprises a sleeve which surrounds said reformable member, said reformable member is elongated.

22. The electronic package of claim **21** wherein said elastic member further comprises a tearable member removably positioned on said sleeve.

23. The electronic package of claim **1** wherein said reformable member comprises a solder ball.

24. The electronic package of claim **1** further comprising another contact pad on said substrate, another reformable member positioned on said other contact pad and another elastic member positioned substantially around said other reformable member.

25. The electronic package of claim **24** wherein said elastic members include a connector therebetween.

26. The electronic package of claim **25** wherein said connector is removable.

27. The electronic package of claim **26** wherein said connector comprises a tearable member removably positioned between said elastic members to align said elastic members with said reformable members.

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